MIT Lincoln Laboratory
ABS Industry Day Presentation

21 June 2001
Greenbelt, MD

ABS Point Design Overview

GOES ABS Industry Day
21 June 2001
Greenbelt, MD

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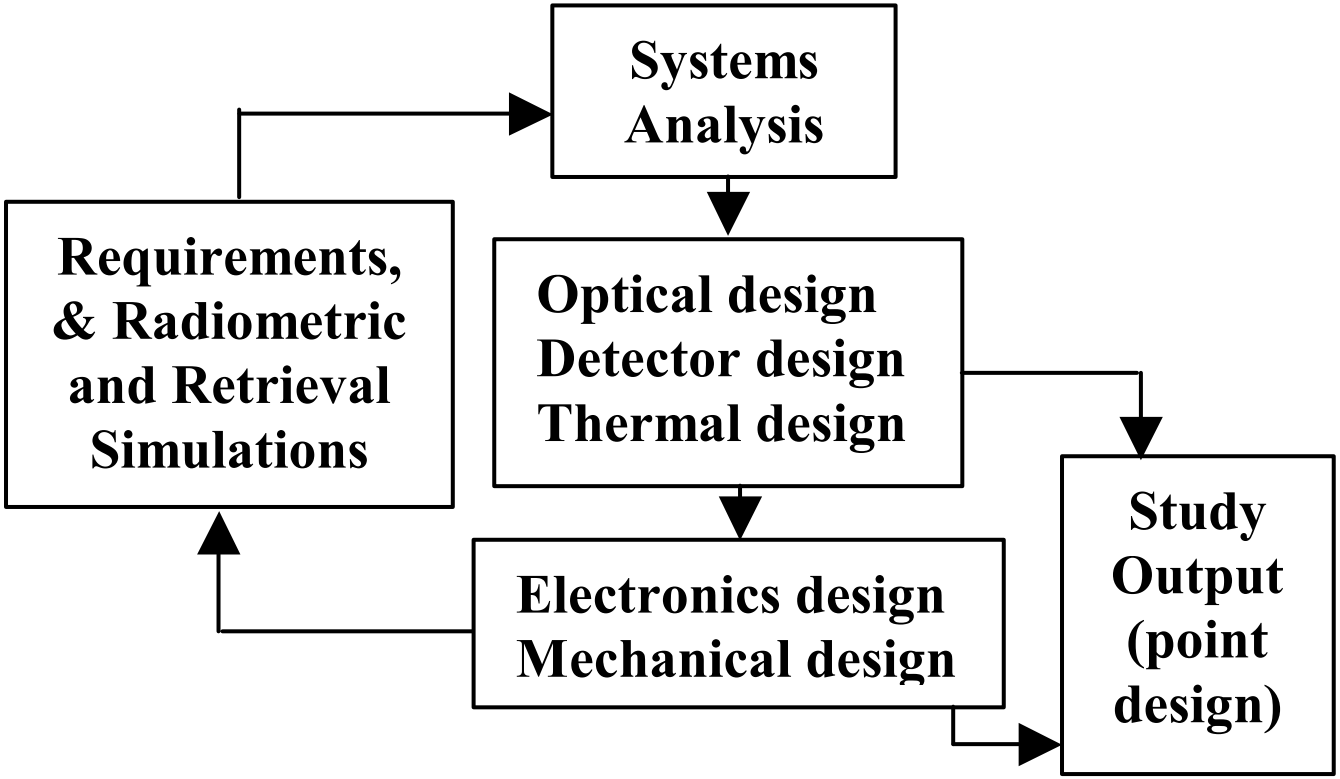
Study Charter

- In January, 2001 a signed NESDIS Technical Requirements Document (TRD) was posted* to contractors as part of a Request for Information (RFI).
  - This TRD represents a substantial upgrade in the quantity and quality of data required from the GOES Advanced Baseline Sounder (ABS).
  - MIT/LL point designs for ABS issued in January, 1999 (Project Report NOAA-24) and April, 2000 (Project Report NOAA-28) were no longer in compliance with ABS requirements.
- MIT/LL was tasked to generate an ABS point design in compliance with TRD requirements.

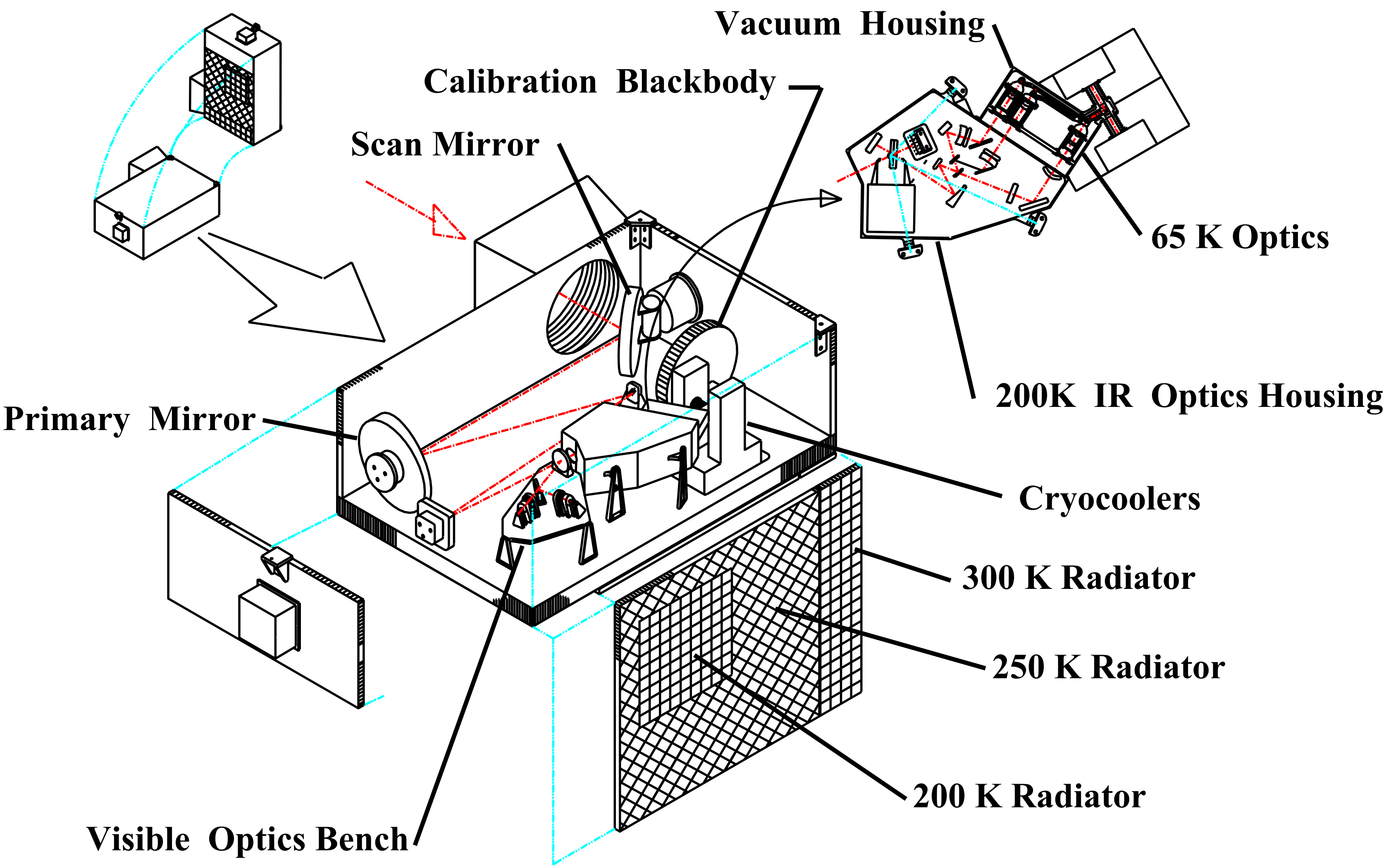
* See http://procurement.nasa.gov/cgi-bin/EPS/synopsis.cgi?acqid=95397

Study Methodology

- Design elements arrived at through an iterative process:



ABS Exploded View



Sensor Mass Estimate

Description	Mass (Kg)
Input aperture cover	5.5
Radiator cover	2.5
Optical bench (3" Al. honeycomb)	11.0
Ambient optics assemblies	13.9
200 K optics assembly	11.2
65 K optics assembly	1.5
Blackbody calibration source	1.2
Scan mirror (SiC 50% LW)	10.2
Scan motor assembly	3.0
Baffles, internal & external	9.1
Housing (1" Al. honeycomb)	16.6
Moving mirror assembly	1.8
Radiation shielding	0.1
Magnetic shielding	0.9
Cryocoolers (2)	8.0
Passive thermal radiators	8.6
Sensor estimate	105.1
20% Contingency	21.0
ABS sensor total mass	~126

System Mass Estimate

- Estimated system mass is ~ 200 kg, divided roughly 2/3 - 1/3 between sensor and power supplies/electronics.

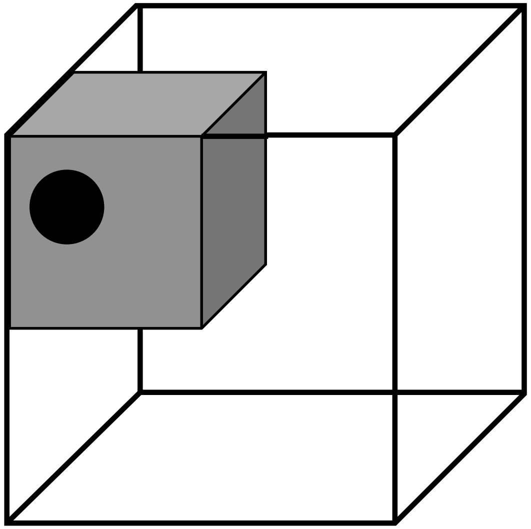
Description	Mass (Kg)
Power supplies (redundant set of 2 in shielded enclosures)	10.0
Sensor control electronics (redundant set of 13 6" x 8" boards at 0.5 kg per board)	13.0
Cryocooler electronics (redundant)	11.0
Signal processing electronics (redundant set of 8 6" x 8" boards)	8.0
Cables (estimate)	4.5
Power supplies & electronics estimate	46.5
20% Contingency	9.3
ABS electronics total mass	~56
ABS sensor total mass	~126
ABS system total mass	~185

System Power Estimate

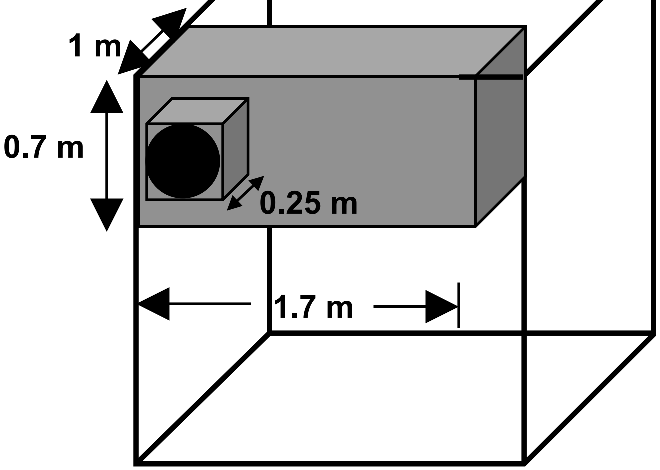
Description	Power	Notes
(Sensor Electronics)	90 Watts	Sunk to sensor
Scan mirror motor	20 W	ambient
Interferometer mirror motor	8 W	ambient
Interferometer metrology	4 W	ambient
IR signal preamplifiers	7.5 W	ambient
Cryocooler compressor	50 W (20 W/W sp. Power)	250 K
(External Electronics)	130 Watts	Sunk to bus (ambient)
Scan mirror servo	2.5 W	
Moving mirror servo	2.0 W	
Instrument controller	1.0 W	
FPA timing and drive	13.5 W	2 CCD's, 3 FPA's
IR A/D & signal processing	28.7 W	Post preamplification
Vis signal processing	0.6 W	
Vis CCD thermal control	4.8 W	2 CCD's
IR FPA thermal control	4.5 W	3 FPA's
Cryocooler electronics	20 W	
Cryocooler EOL margin	20 W	
Electronics power supply	32.5 W	
TOTAL	~220 Watts	

ABS Volume

- The design goal was to retain a ~ 1m cube form factor.
  - Spacecraft assumed to be a 2m cube.
  - ABI and ABS assumed to occupy 1/8 of spacecraft volume.
- Optics drives volume: an optical design with a 480 x 160 km field could have fit into this 1m^3 volume.
  - Could not simultaneously meet coverage rate and NEdN.
- The final design provides a 530 x 250 km IR field.
  - Accomodates 480 x 220 km FPA footprint with upgrade path.



Design goal



Final design

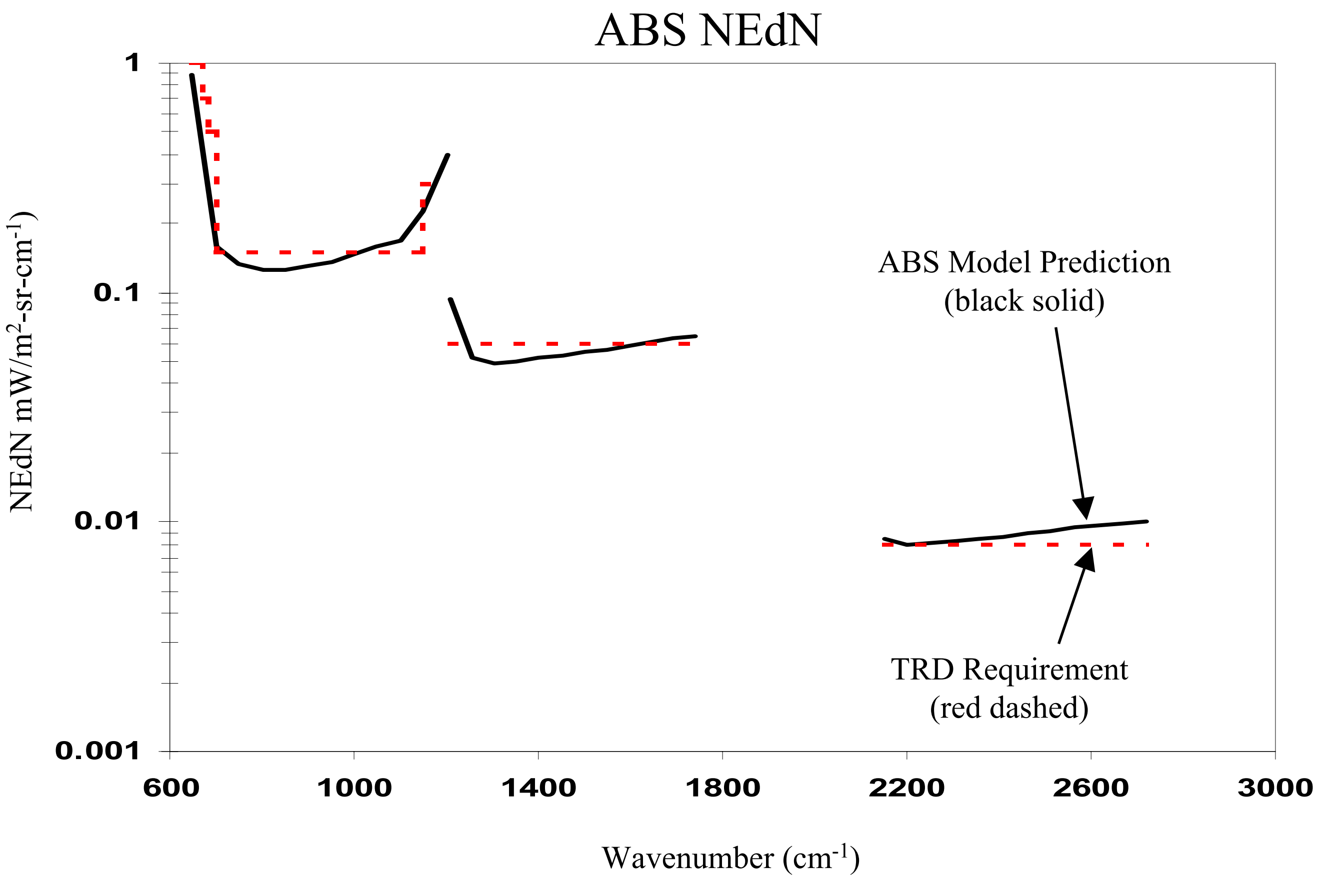
ABS Data Rate

- Data per stare
  - IR: 2x compression, bit trimmed, decimation factors: 20(LW),10(MW),10(SW)
  - Visible: 2x compression, lossless
  - LWIR: (16+2) bits/pix^2 x (22x48) pix^2 x 1034 sam x (1/3)Hz x 2/2 = 6.55 Mbps
  - MWIR: (16+2) bits/pix^2 x (22x48) pix^2 x 517 sam x (1/3)Hz x 2/2 = 3.27 Mbps
  - SWIR: (12+2) bits/pix^2 x (22x48) pix^2 x 258 sam x (1/3)Hz x 2/2 = 1.27 Mbps
  - Visible: 14 bits/pix^2 x 220 x 480 pix^2 x (1/3) Hz x ½ = 0.25 Mbps
  - Data in a visible image is < 3% of data in the IR (assuming 1 array is transmitted).
- Data rate
  - Total: 11.35 Mbps before buffering
  - By buffering data during entire hour, data rate can be reduced

    87.5% of total time represents data collection time (i.e.. step time and slew time)

    Thus 12.5% of interferogram data can be buffered for a maximum of 4 rows, containing a maximum of 168 steps, requiring a maximum of 715 Mbits of storage.
  - Total (Vis+IR): 9.93 Mbps before buffering, which is < 10 Mbps downlink

ABS Median Pixel NEdN Model Results



Key Parameters:

Instrument
8 km FOV 10 km pitch
30 cm aperture
1.55 um laser metrology
16 bit ADC, 0.5 MHz
1 hour coverage time
<10 Mbps data rate

FPA
22 x 48 FPA
T = 65 K
58 um pixels 73 um pitch
3.8e8 e- LWIR well depth
up to 16 low outputs
0.45 Mpix/sec per output
up to 6.9 kHz frame rate

Optics
LW 650-1200
MW 1210 - 1740
SW 2150 - 2721

200 K cooled optics
f/0.86 all reflective
ZnSe beamsplitter

Point Design Summary

- The point design presented here meets all TRD requirements.
- Challenging requirements have led to a challenging design.
  - More inclusion of technological and fabrication risk than previous designs.
  - Heavy dependence on GIFTS to validate key technologies.
- Incorporation of ABS and ABI on a common platform is challenging, given instrument parameters.
  - 530 x 500 vis. Field / 530 x 250 IR field / 480 x 220 IR FPA field (possible upgrade path).
  - NEdN (NESR) of 0.13 mW/(m^2 sr cm^{-1}) at LWIR band center assuming median FPA D* and 289 K blackbody.
  - 30 cm (12 inch) aperture diameter.
  - Mass = 185 kg.
  - Power = 220 W.
  - Volume = 0.7 x 1.25 x 1.7 m (longest in E/W direction).
  - Data rate = 9.93 Mbps.

MIT/LL ABS Point Designs

- 1999
  - Coverage of 3000 x 5000 km in 30 min.
  - NEdN required [mW/(m^2 sr cm^{-1})]:
    - LW: 0.5 , MW: 0.1, SW: 0.05
  - 15 cm Aperture, 80 kg, 70 W, 0.6 x 0.6 x 0.7 m passively cooled FTS.
- 2000
  - Same coverage and NEdN with >90% ensquared energy
  - 25 cm Aperture, 110 kg, 90 W, 0.6 x 0.8 x 0.8 m passively cooled FTS.
- 2001
  - Coverage of 9640 km Dia. In 60 min. (~2.5 times greater)
  - NEdN required:
    - LW: 0.15 , MW: 0.06, SW: 0.008 (~2 to 6 times less noise)
  - 30 cm Aperture, 185 kg, 220 W, 0.7 x 1.25 x 1.7 m actively cooled FTS.

ABS Operations

GOES ABS Industry Day
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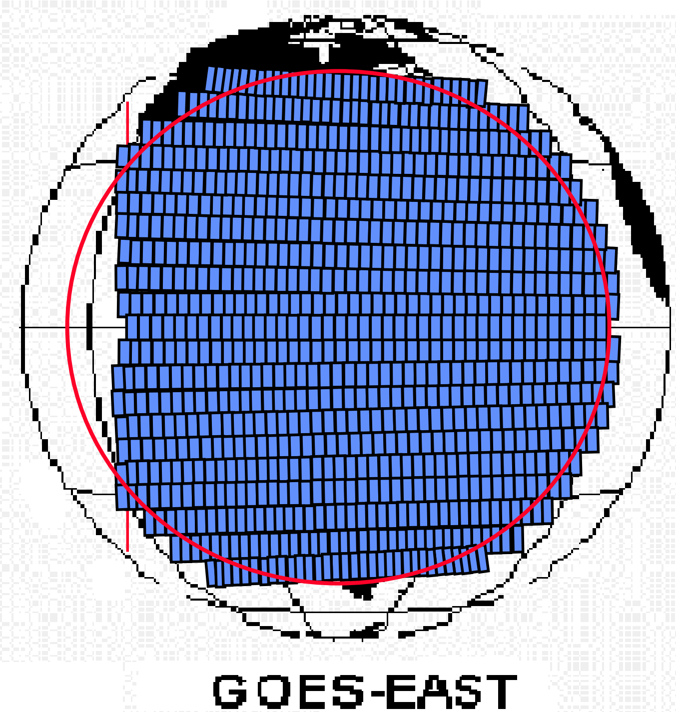
Monica Coakley

Outline

- Scan coverage requirements
- Scan plan
- Calibration optimization
- Metrology
- Data rate
- Visible channel cloud clearing performance
- Visible channel star sensing performance
- Summary

ABS Scan Plan Overview

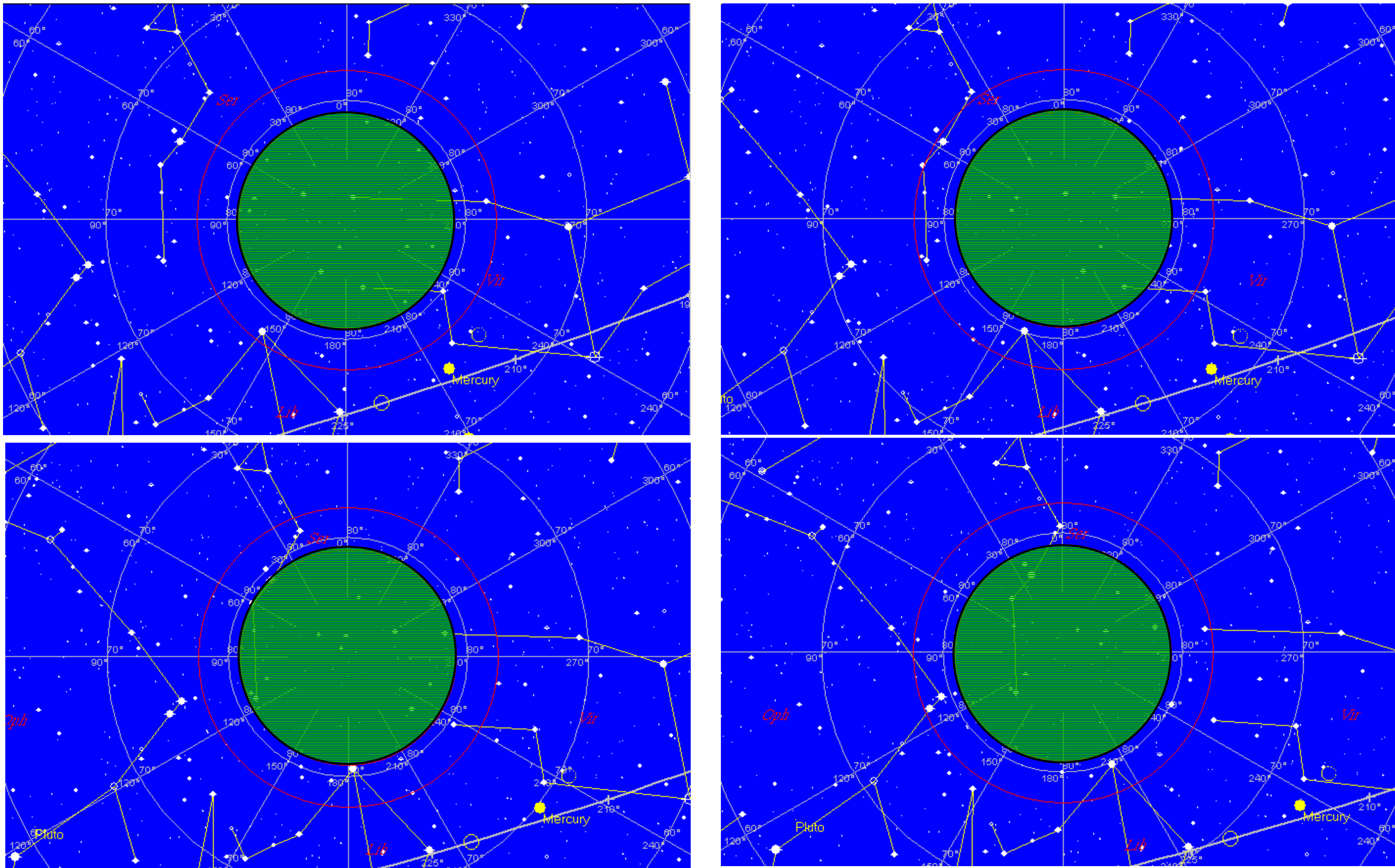


- Required coverage of 62 degrees local zenith angle per hour sets coverage rate.
- Coverage rate ~2.4 x original ABS, which implies ~2.4 x 2 x CONUS and all calibrations and star tracking in 1 hour.
- Transmit data rate requirement of 10Mbps is also met.
- Using 22X48 IR array covering 220 km x480 km per step
- Using realistic slew and settle values set by current sounder (scaled star tracki distance to permit 8 degree motion beyond earth disk.)
- Using realistic step and settle values (industry estimate) of 0.240 sec
- For spacecraft accommodation on current bus, assuming both mirror and optical axis of telescope are parallel

Star Tracking Operations

- Eight star tacking operations are required in 1 hour
  - Assumed star tracking will not interrupt a row of data
  - Star tracking will use nearby stars of 7th magnitude or brighter
  - A look-up table/database is needed to determine which star to detect each time within ~ 8 degree annulus surrounding earth
    - Stars drifting through annulus during the hour.

GOES East View Nov 3, 2002, 11:56 PM–12:41 AM shows star motion during hour



Scan Plan: Overlapping Footprints

- **Image rotation of array does not permit the projected footprints of the array to be exactly square to each other.**
- **To avoid gaps in coverage, the array steps can be oversized**
  - **Overlaping the footprints in this way requires more total steps (+13.8%)**

    No gaps (overlapped) : 840 steps (before cal)

    Gaps (not overlapped): 731 steps (before cal)
  - **Scan efficiency:**

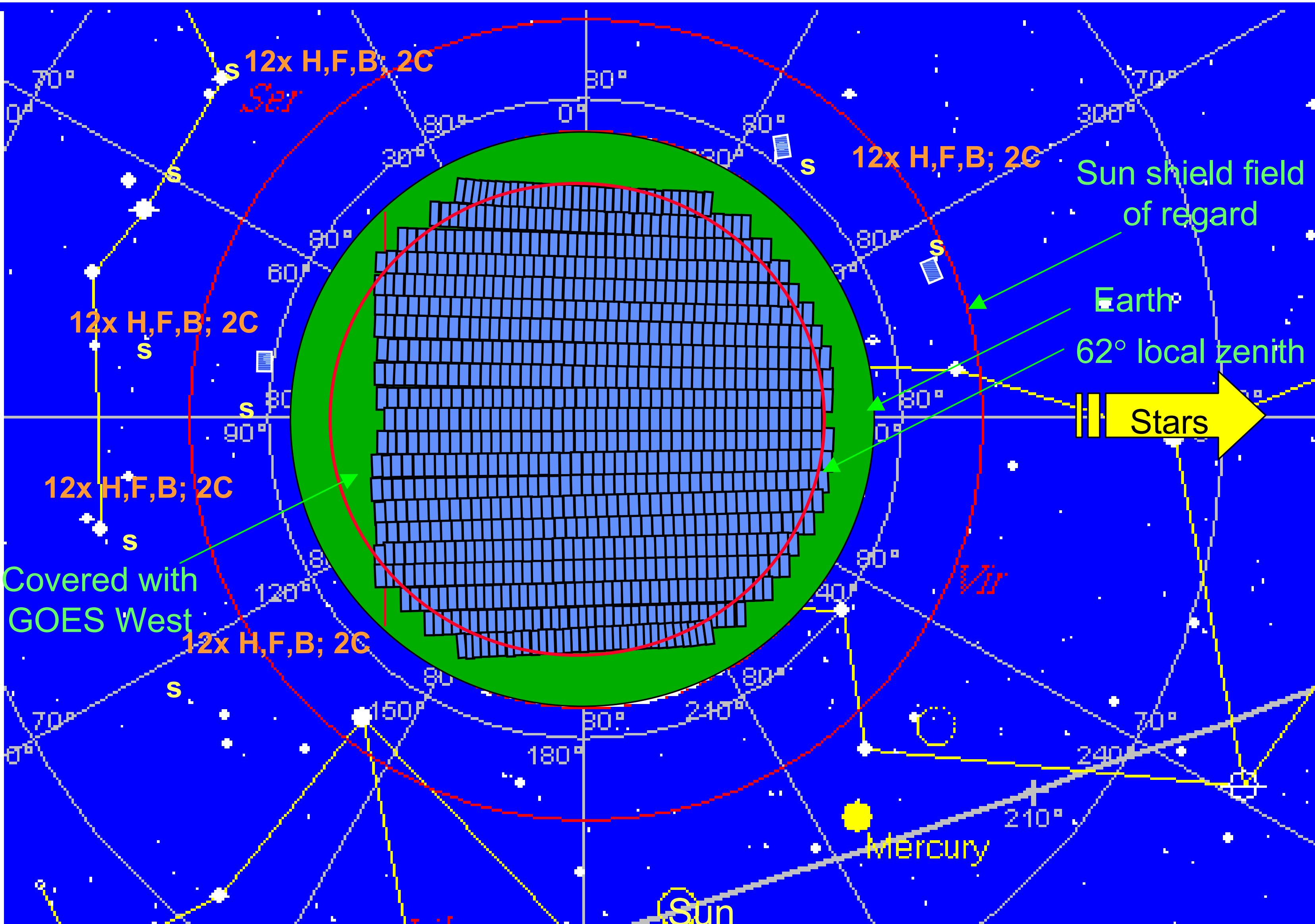
$$\frac{\dfrac{\text{Footprint size}}{t_{int}(\text{sec})} * \dfrac{3600\,\text{sec}}{\text{hour}}}{\text{Total coverage area}} = \text{fraction of hour spent observing earth}$$

  - **Overlaping reduces effective footprint size, thereby reducing scan efficiency and slowing coverage rate.**
- ***Permitting gaps between footprints increases the overall scan efficiency from 60% to 68% thereby either improving NEDN by <10% and retrievals by <2% or increasing the coverage area by ~97 steps (~.6xCONUS).***

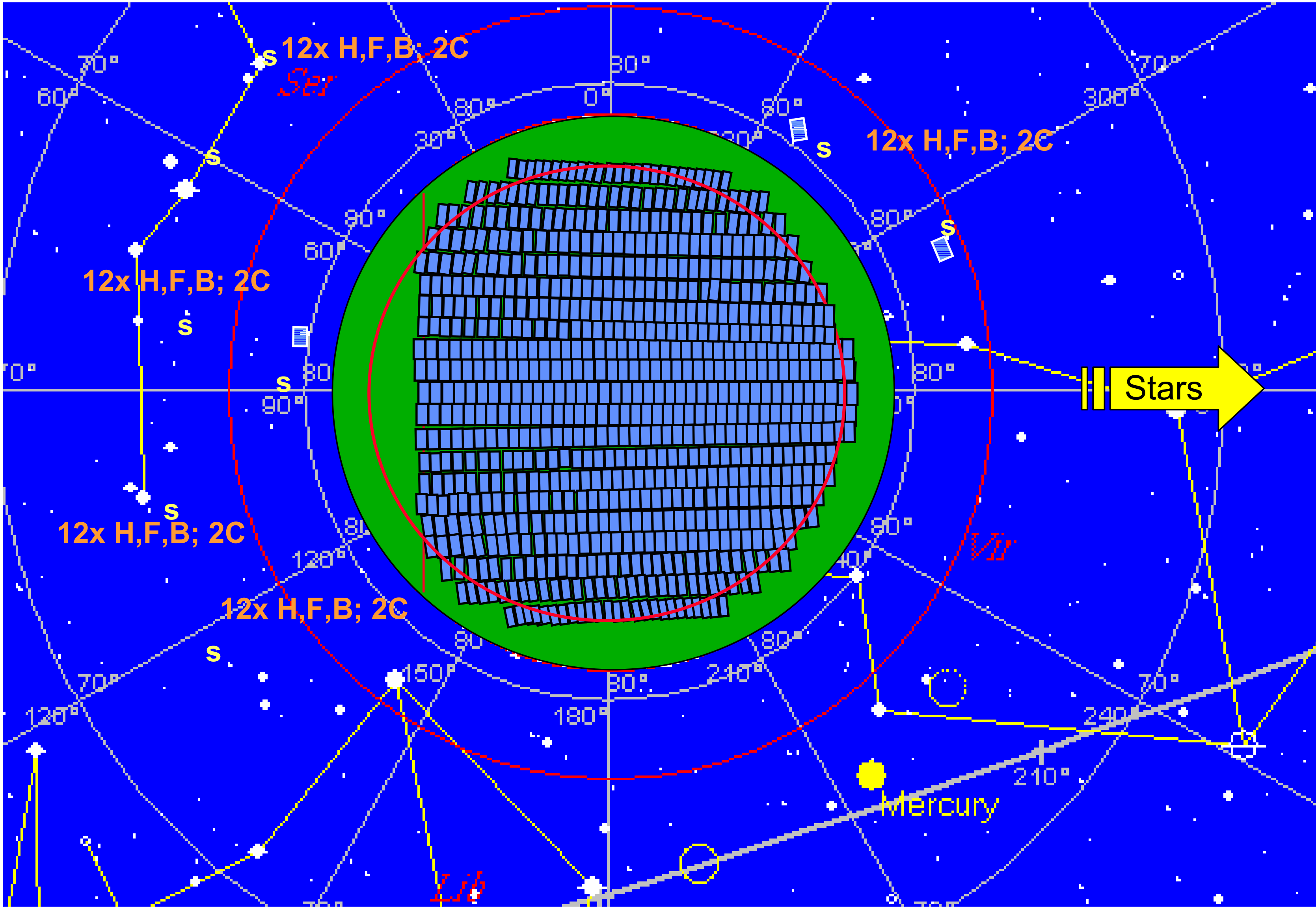
Scan plan coverage comparison

Scan Plan Property	No Gap Coverage	Gap Coverage
Number of rows	21	21
Steps in longest row	46, requiring 2.5 minutes	39, requiring 2.4 minutes
Steps in shortest row	32	25
Maximum gap	0 pixels / 22 pixels 0 pixels / 48 pixels	4 pixels / 22 pixels >1 pixels / 48 pixels
Stare time per step	3.0 sec	3.4 sec
Total time for step	3.24 sec	3.64 sec
Total number of steps	840	731
Calibrations stops (maximum of 15 minutes apart, require ~20% of hour)	38 interferograms (12F,12B, 12H, 2C) over 2.3 minutes	38 interferograms (12F, 12B, 12H, 2C) over 2.5 minutes
CONUS coverage time (est.)	12.7 minutes	13.0 minutes

Overlap Scan Plan (25º annulus=17.3º for earth+7.7º for stars) (7th mag shown)

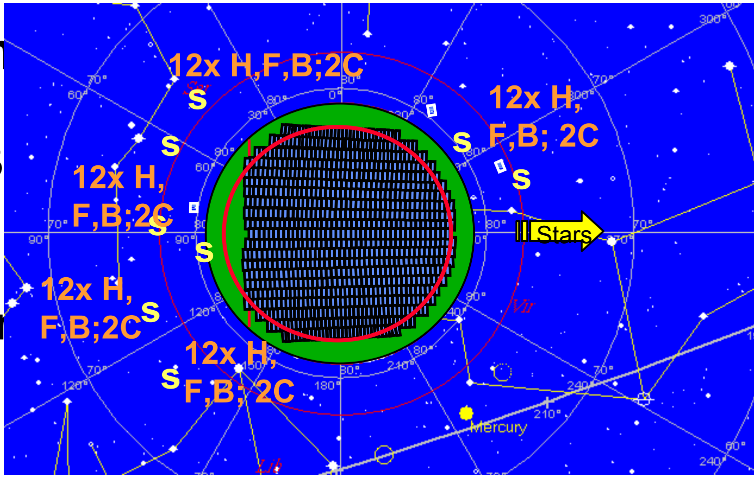


No Overlap Scan Plan (25º annulus=17.3º for earth+7.7º for stars) (7th mag shown)



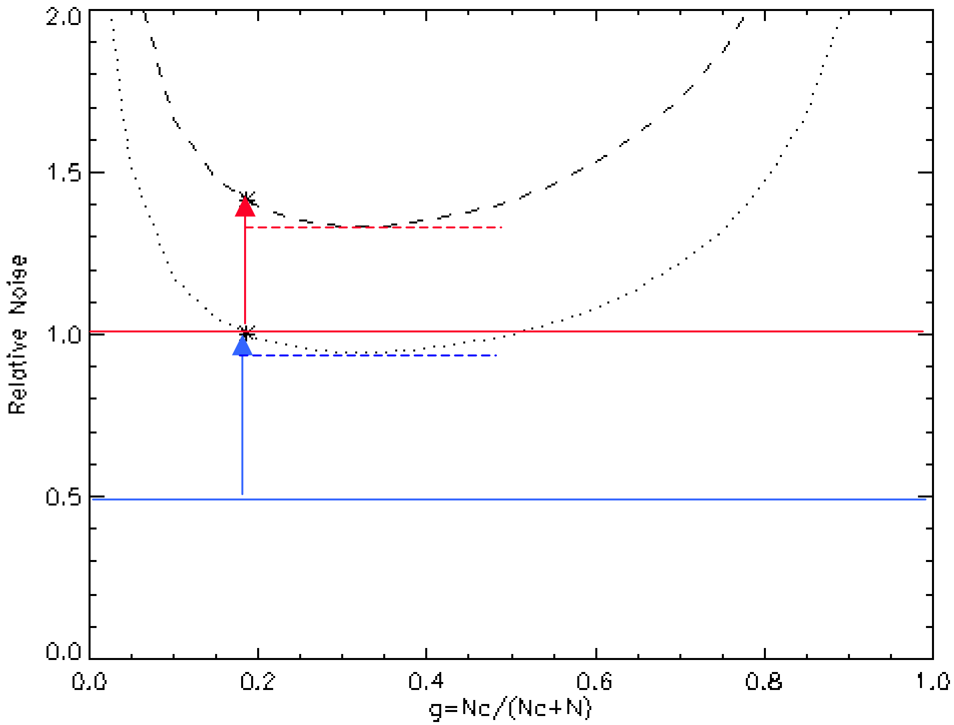
ABS Calibration Plan

- Utilize 4 calibrations per hour (5 maximun
  each having:
  - Forward & Backward interferograms (F,B
  - Hot blackbody and Cold (space) looks (H
  - 12 interferograms of each type averaged improve calibration by approaching minir possible noise
  - Only two cold calibration permitted to reduce data rate to less than 10 Mbps; simulated calibration performance not strongly sensitive to number of cold calibrations (Kelly, private comm.)



- Calibration are combined with star tracking operations.
  - 4 (5 max) of the required 8 star tacking operations support calibrations
  - During these star trackings/calibrations
    - 7th magnitude stars can be detected
    - A look-up table/database is needed to determine which star to detect each time within ~ 8 degree annulus surrounding earth.

ABS Calibration



$$g = \frac{\text{Number of calibrations}}{\text{Number of calibrations} + \text{Number of observations}}$$

- **12 stares at each to improve calibration to within 6% of minimum achievable calibration noise.**

Outline

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- Visible channel star sensing performance
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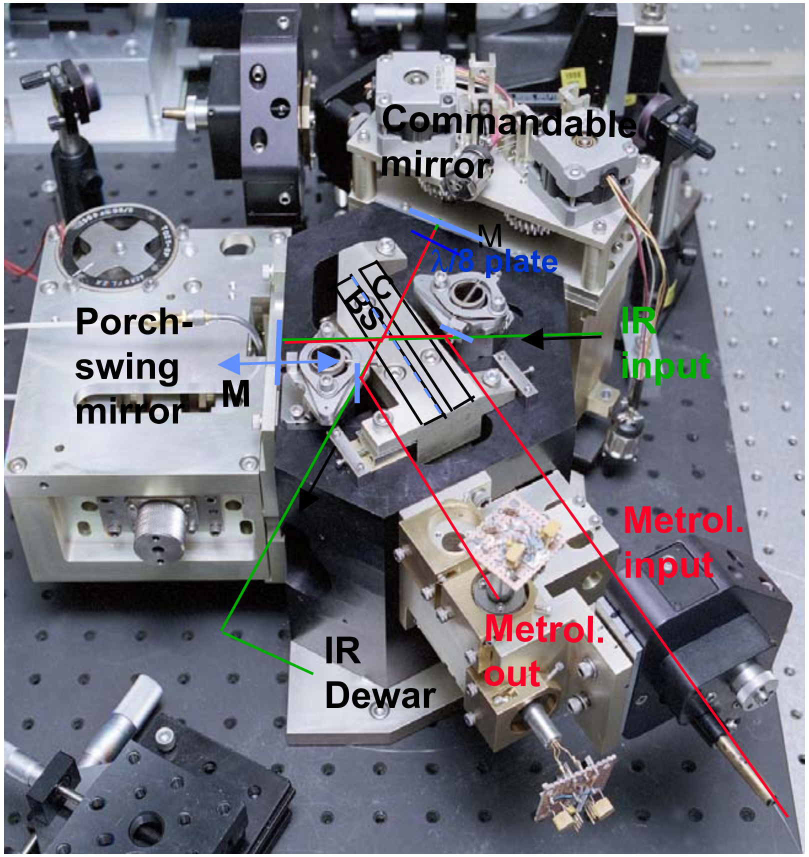
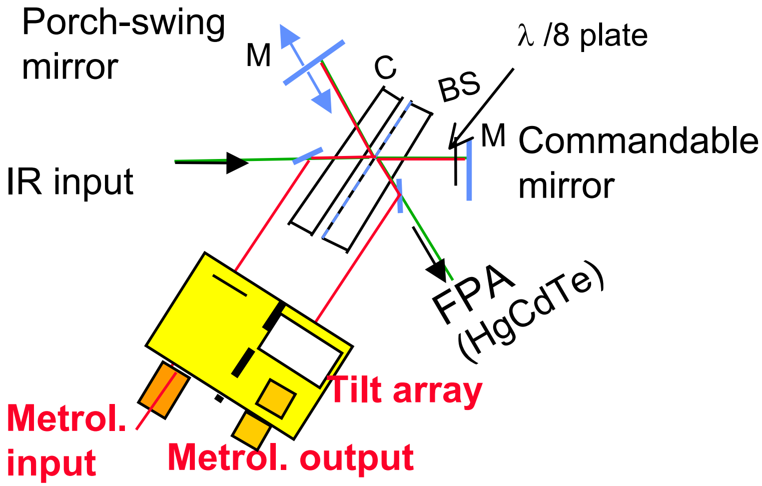
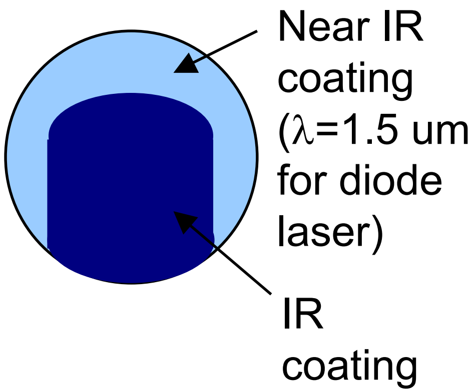
ABS Metrology System draws on GHIS

- ABS Design metrology draws on GHIS metrology system.
  - Laser input from fiber sees polarizer at 45 degrees.
  - Lambda/8 wave plate in one arm of interferometer changes phase
  - Two polarizers set at 90 degrees analyze output for two single element detectors
- Interferometer testing set-up is currently testing tilt correction using metrology array

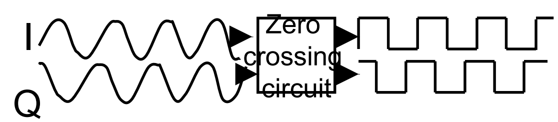


ABS Metrology: Layout





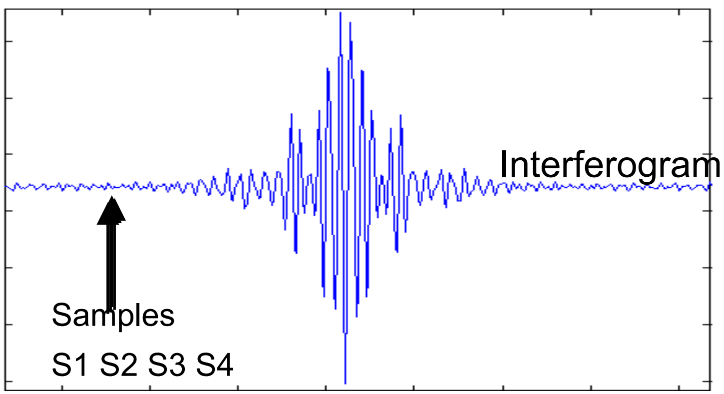
- **Two metrology beams are formed (one shown) and enter interferometer**
  - **Both are transmitted by the near IR coated region of the beamsplitter and compensator, located parallel to and above the IR beam.**
  - **Linearly polarized upper beam sees a phase shift of 90 degrees from λ/8 plate. Quadrature TTL signal formed from zero crossings of polarization components I and Q.**

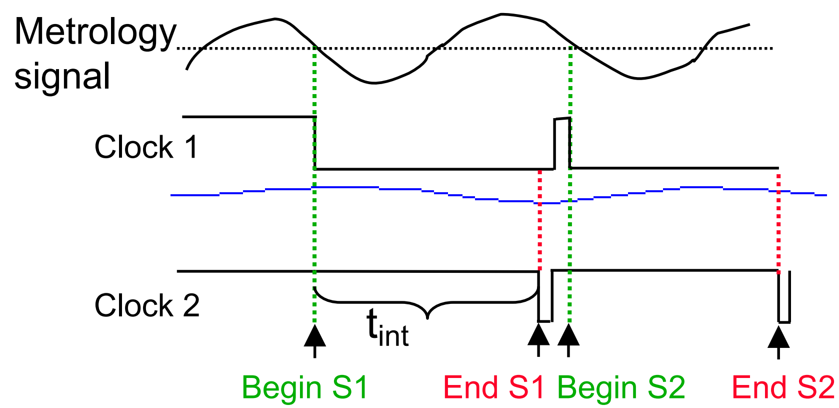


  - **Unpolarized lower beam used for tilt sensing**
    - **Moving mirror tilt will be recorded with an array detector (InGaAs) and tilt error in microradians will be transmitted to the ground.**
    - **The array system uses the metrology beam modulation to measure tilt. For a 7 μrad or 4 μrad tilt precisions, require S/N~200 or 600 respectively (5mW vs 100 mW laser).**

ABS Metrology: Sampling

- **Metrology system**
  - **Provides a regular spectral sampling interval for the start of integration.**
    - **End of integration time is determined by a fixed time.**
    - **To first order t_{int} is determined by uniform spectral steps but the second order effect of a variable mirror velocity can introduce a ~ .1% mirror velocity fluctuation error.**





  - **Provides a measure of the position of the moving mirror**
    - **Quadrature signal pulses are counted in servo electronics to determine mirror turn around.**
  - **Provides quadrature signal pulses that are counted for IR signal decimation.**

Metrology Laser Issues

- **Metrology laser**
  - FPA sampling could utilize a laser of wavelength of 1.550 um.
  - Diode lasers with tunable output from 1.520 um to 1.570 um are common for optical communications
  - However, it is not clear that a COTS diode laser will be sufficient for ABS requirements. Further work is required to address concerns for
    - Stability
    - Lifetime
    - Power
    - Space qualification
  - A COTS diode laser (1.532 um) was modified by NASA Goddard for GHIS
  - Other programs/missions will be developing long lifetime lasers for their needs, so ABS will utilize those development efforts.

ABS Data Rate

- Data per stare
  - IR: 2x compression, bit trimmed, decimation factors: 20(LW),10(MW),10(SW)
  - Visible: 2x compression, lossless
  - LWIR: (16+2) bits/pix^2 x (22x48) pix^2 x 1034 sam x (1/3)Hz x 2/2 = 6.55 Mbps
  - MWIR: (16+2) bits/pix^2 x (22x48) pix^2 x 517 sam x (1/3)Hz x 2/2 = 3.27 Mbps
  - SWIR: (12+2) bits/pix^2 x (22x48) pix^2 x 258 sam x (1/3)Hz x 2/2 = 1.27 Mbps
  - Visible: 14 bits/pix^2 x 220 x 480 pix^2 x (1/3) Hz x ½ = 0.25 Mbps
  - Data in a visible image is < 3% of data in the IR (assuming 1 array is transmitted).
- Data rate
  - Total: 11.35 Mbps before buffering
  - By buffering data during entire hour, data rate can be reduced

    87.5% of total time represents data collection time (i.e.. step time and slew time)

    Thus 12.5% of interferogram data can be buffered for a maximum of 4 rows, containing a maximum of 168 steps, requiring a maximum of 715 Mbits of storage.
  - Total (Vis+IR): 9.93 Mbps before buffering, which is < 10 Mbps downlink

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ABS Visible: CCD Properties

- Required visible channel resolution (ABS TRD): 1 km
- For a 22 x 48 IR array, need uncommon format 220 x 480 CCD
  - Use more common larger array but only transmit part of it. (Visible data rate less than 3% of IR data rate)
    - Unlike IR FPA's, CCD's must shift charge across array before shifting out.
      - Charge is still collected during shifting time.
      - Mechanical or electrical shutter may fail
      - Shift charge quickly so that Tshift < 1/10 of Tint
      - Lengthen Tint for daytime flux levels by using 5.5% beamsplitter reflection for daylight and use 94.5% beamsplitter transmission with another CCD for low light.
  - Use part of each 1024 x 1024 array (Philips FFT1010, frame transfer)
    - 300,000 e^- per pixel, linear region (Philips FFT1010, frame transfer).
    - Q.E. = 30%
    - Read noise: 18 e/pix
    - Dark current: 225 e/(pixel sec), assuming 25 °C operation (TE stabilized)

ABS Visible: Simulation (2 CCDs for daytime and nighttime, 1 km resolution)

- **Baseline --- Daytime cloud coverage (100% albedo):**
  - Achievable with a 5.5% reflection from BS (2.4% overall optical efficiency)

    Permits shift-to-buffer time to be < 10% of integration time by reducing flux 18x.

    S/N = 548 in 3 ms over (1 km)^2
- **Baseline--- Low light coverage from 94.5% BS transmission (43 % overall optical efficiency)**

  Full moon:

  S/N = 115 in 3 sec over (1 km)^2

  S/N = 530 in 2.5 sec over (5 km)^2 (if reduced resolution is permitted)

  Quarter moon:

  S/N = 29 in 3 sec over (1 km)^2

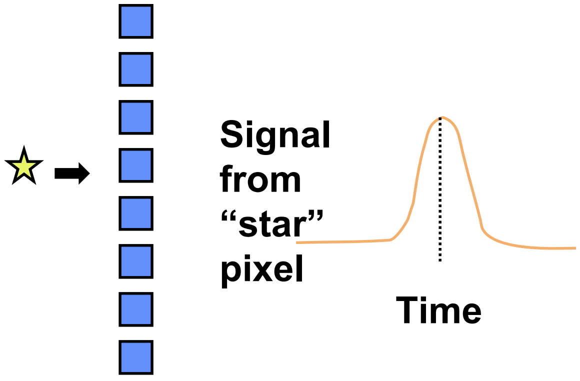
  S/N = 158 in 3 sec over (5 km)^2 (if reduced resolution is permitted)

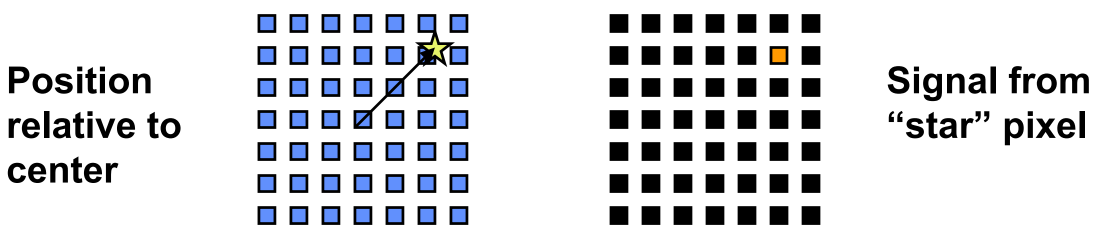
  Twilight:

Sunset	(0 degrees),	S/N = 540 in 0.035 sec over (1 km)^2
Civil Twilight	(-6 degrees),	S/N = 221 in 3 sec over (5 km)^2
Nautical Twilight	(-12 degrees),	S/N = 13 in 3 sec over (1 km)^2
		S/N = 77 in 3 sec over (5 km)^2
Astron. Twilight	(-18 degrees),	S/N = 1 in 3 sec over (1 km)^2
		S/N = 8 in 3 sec over (5 km)^2

ABS: Visible channel star sensing

- Star Sense required: current GOES method
  - Mirror rotated to space and stopped.
  - Star drifts through in 7-sec typical stare
  - Each integration time is 9 ms with S/N ~10
- Star Sensing simplified with CCD detector
  - Utilize rectangular portion of array for position information at time of integration.





  - Permitting the star’s image to form a streak on the array and centroiding; star has moved over 2 pixels

    S/N = 158 in 1 sec for a 4th magnitude, S/N = 34 in 1 sec for 7th magnitude.
    For stars with mag <1.5, use tint = 0.5 sec.

    Margin in integration time for end of life since IR integration times are ~3x.

ABS Operations Summary

- **Requirement for scan rate covering 62 degrees local zenith angle in one hour is met using scan plan with no gaps.**
  - **Overlapping of ground footprints to avoid gaps represents a scan inefficiency of 13.8%.**
  - **Gaps are not explicitly excluding in TRD, although they may be excluded in PORD.**
  - ***Estimated CONUS coverage with no gaps is 12.7 minutes (26x7steps), or 4.7 CONUS's in an hour (~2.4 times rate of Jan. 1998 ABS design)***
- **Calibrations occur simultaneously with star tracking operations.**
  - **Maximum of five planned per hour**
  - **All calibration "stops" have 38 interferograms with 12 of each of the following types: forward, backwards, and hot blackbody, with 2 cold space (recent study)**
  - **Seventh magnitude or greater stars are observed for 1 second using visible channel. Centroiding is applied.**

ABS Operations Summary (cont'd)

- Data rate of 10 Mbps is met through 2x compression in visible and IR, bit-trimming in IR and buffering data over the entire hour.
- ABS Metrology system uses GHIS heritage of fiber input and polarizers and 1.5 um laser. However, further work is required to investigate amount of modifications required for COTS diode laser for ABS requirements for stability, lifetime, power, and space qualification.
- Two visible arrays together will a beamsplitter will afford daytime and low light cloud clearing. With reduced resolution, some nighttime coverage is possible.

GOES Advanced Baseline Sounder (ABS) Optical Design

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Danette Ryan-Howard
MIT Lincoln Laboratory

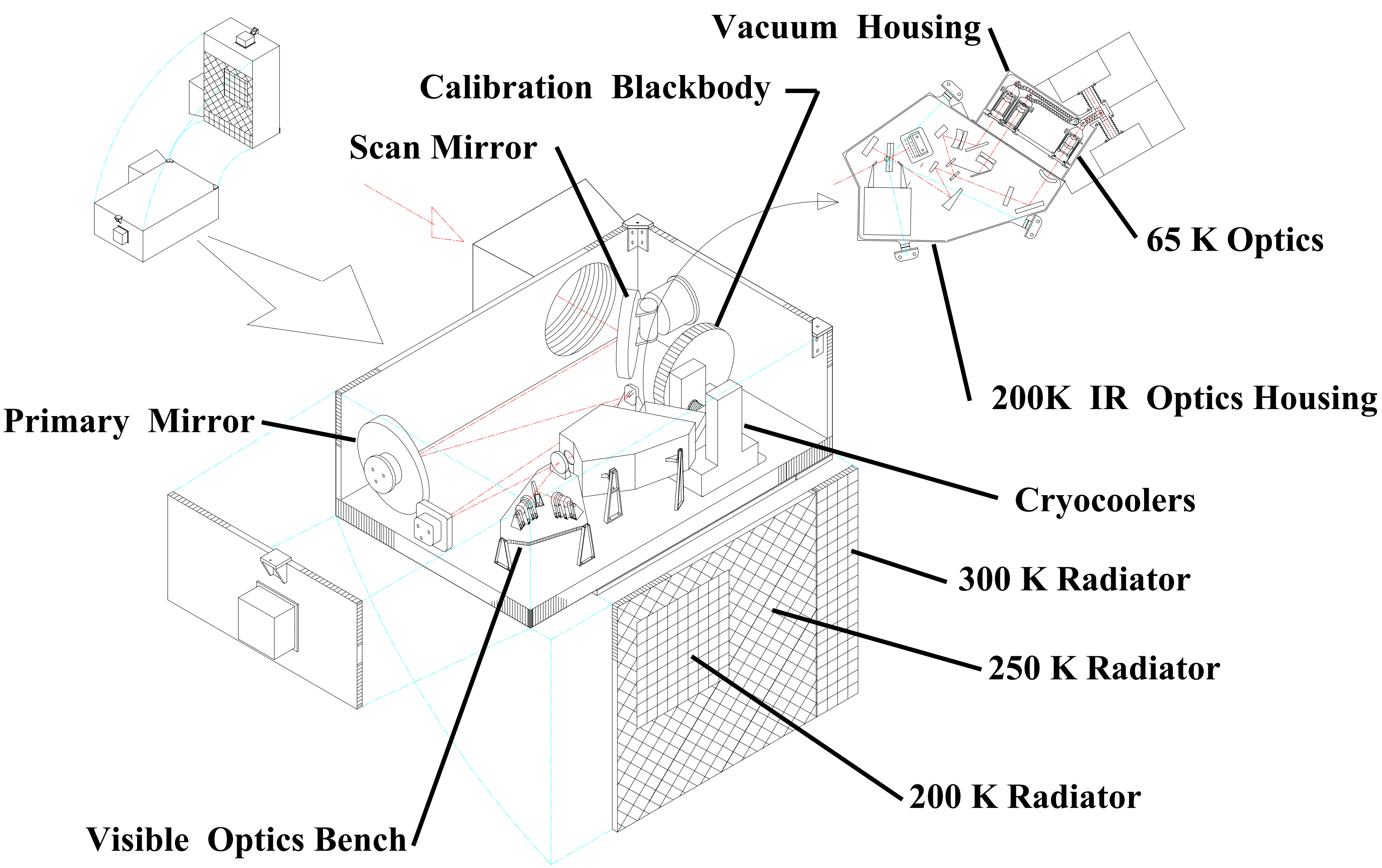
Outline

- ➢ Introduction.
- System volume progression.
- Optical performance of point design.
  - Visible Optics
  - Infrared Optics
- Summary.

2001 ABS Point Design

- 30 cm (12 inch) aperture diameter.
- Two visible channels with 220 x 480-km FOV.
  - Input telescope and visible optics accommodate 500 x 530-km FOV.
- Three infrared channels with 220 x 480 km FOV.
  - Aft optics accommodate 250 x 530-km FOV.
- Fourier Transform Spectrometer
- Cryocoolers and passive radiators for cooling.
  - Active cooling eliminates need to locate IR focal planes on N/S face.
- Mass/volume = 185 kg / 1.7 x 1.25 x 0.7 m.

ABS Exploded View



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- ➢ System volume progression.
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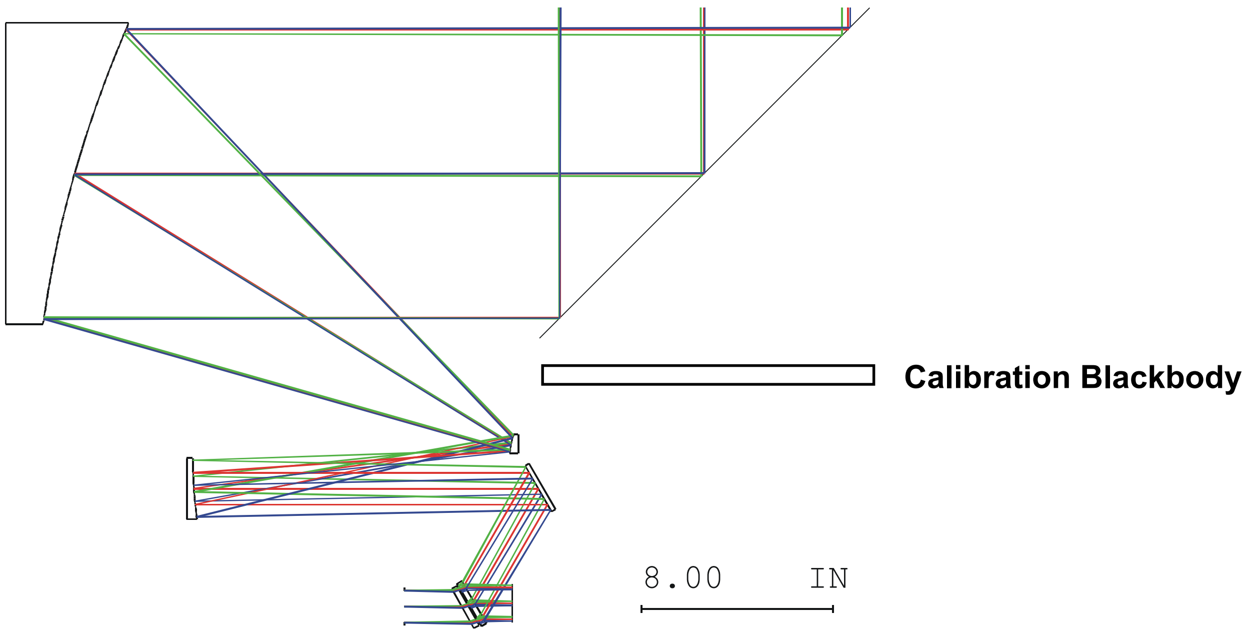
Input Telescope

- Three-mirror off-axis design with common centerline.
- 160 x 480-km field-of-view.
- Volume = 36” x 22” x 13” (0.9 x 0.6 x 0.4 m)



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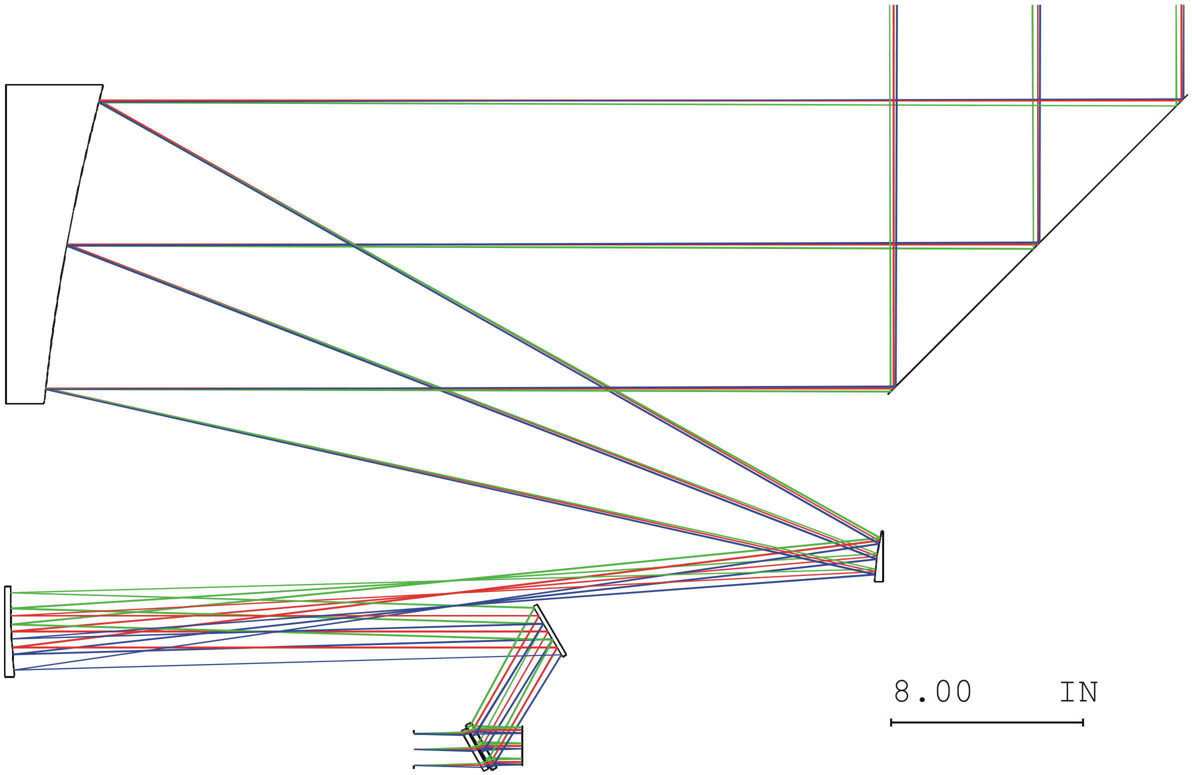
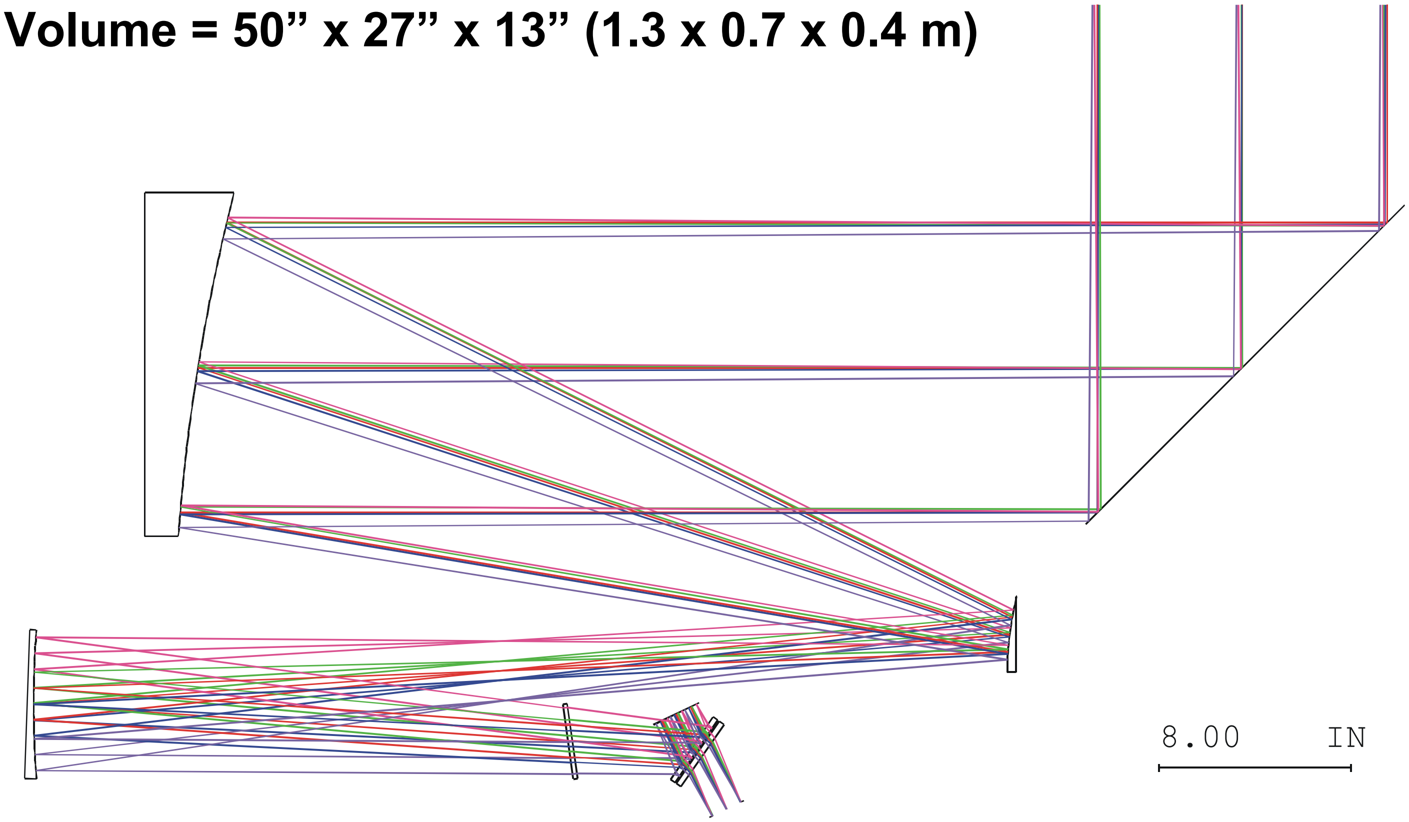
- Three-mirror off-axis design with common centerline.
- 220 x 530-km field-of-view.
- Volume = 50” x 22” x 13” (1.3 x 0.6 x 0.4 m)



Input Telescope

- Three-mirror off-axis design (tertiary tilted).
- 500 x 530-km field-of-view.
- Volume = 50” x 27” x 13” (1.3 x 0.7 x 0.4 m)



Input Telescope Volume

Field-of-View	160 x 480 km	220 x 530 km	500 x 530 km
Input Telescope Volume	36” x 22” x 13”	50” x 22” x 13”	50” x 27” x 13”

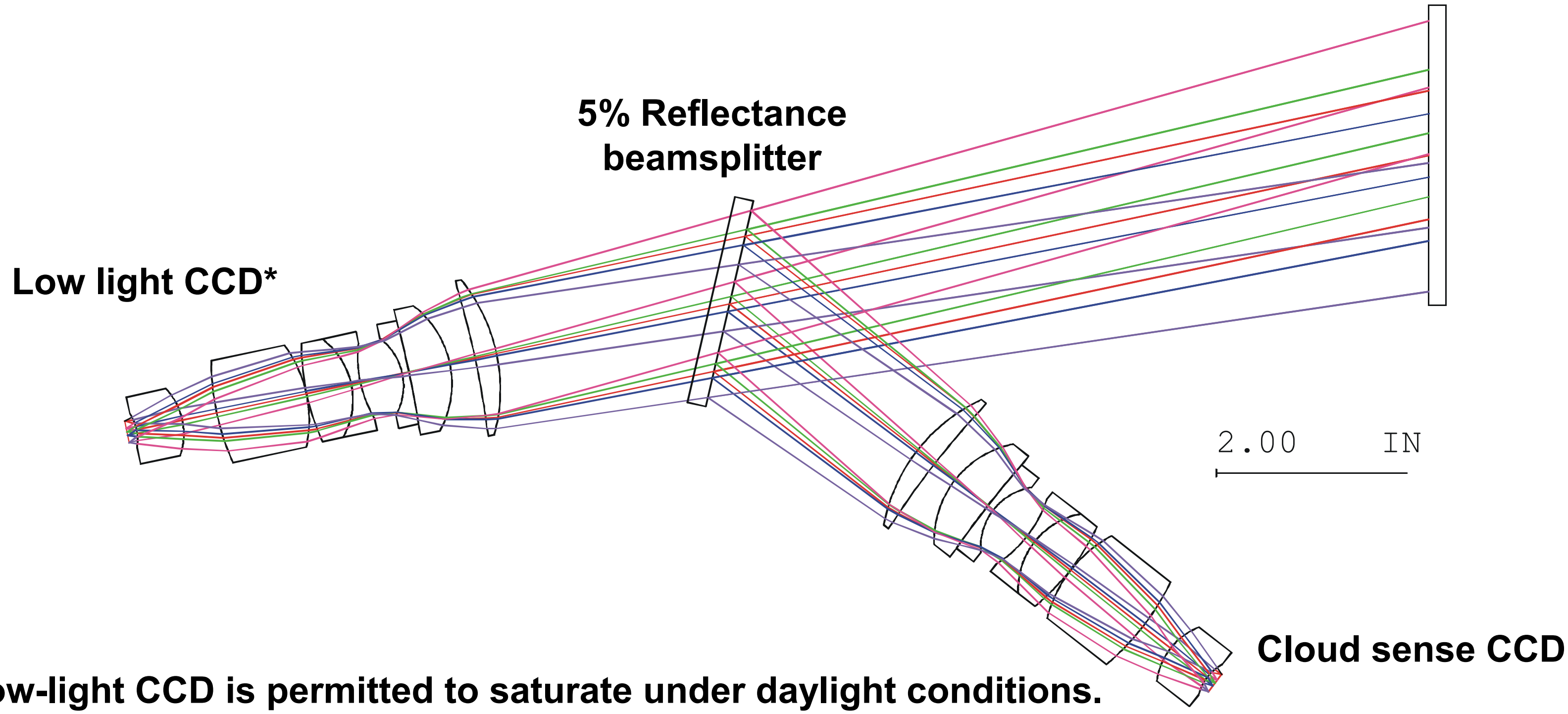
Selected to allow field-of-view growth path

Outline

- Introduction.
- System volume progression.
- ➢ Optical performance of point design.
  – Visible Optics
  – Infrared Optics
- Point design summary and notes.

Visible Channel

- 500 x 530-km field-of-view.
- Design waveband is 500 – 700 nm.
- 1-km resolution.
- Visible channel images scene to two CCD's:
  - CCD optimized for daytime cloud sensing.
  - Low-light CCD* for star sensing and low-light imaging.

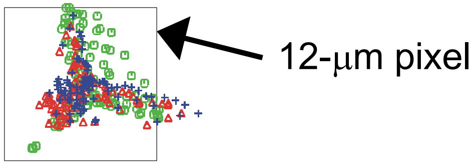


*Low-light CCD is permitted to saturate under daylight conditions.

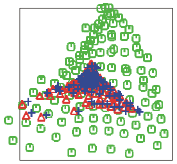
Visible Channel Performance

- 500 x 530-km field-of-view.
- Design waveband is 500 – 700 nm.
- Not a diffraction-limited optical design
- Geometrical spot is matched to 12-µm pixel

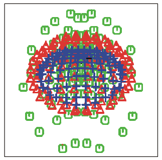
Corner of field-of-view
(500 x 530 km)



Corner of field-of-view
(220 x 480 km)

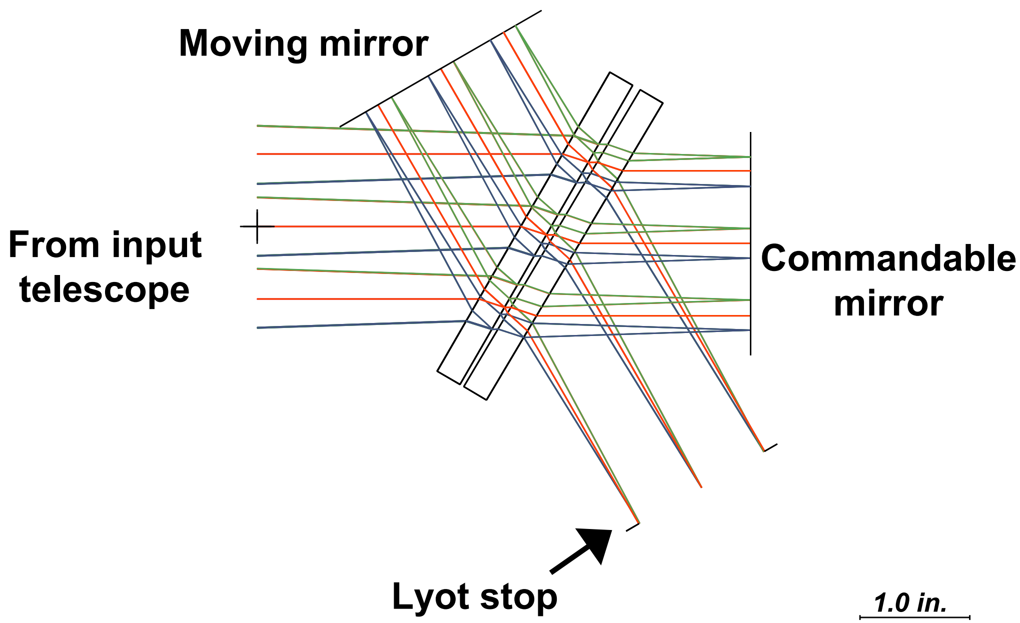


On-axis



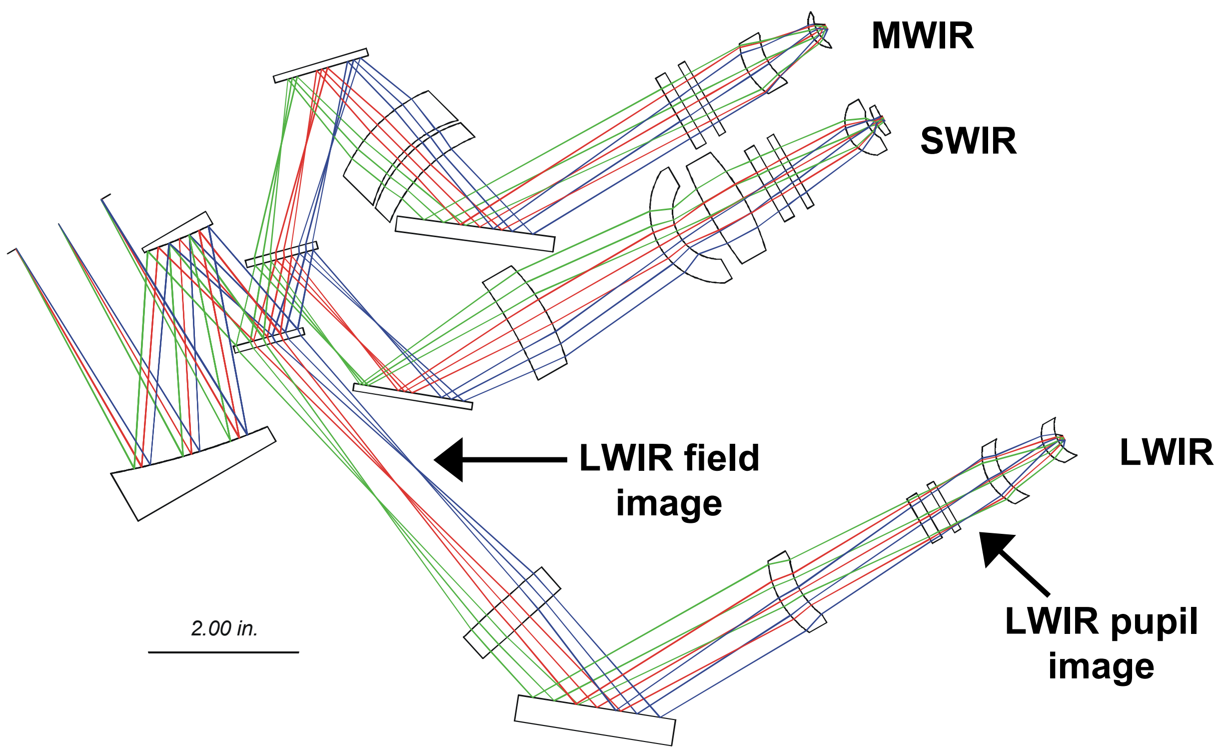
IR Michelson Interferometer

- 3.3 cm diameter beam.
- ZnSe beamsplitter/compensator.
- Metrology beams injected above/below IR beam.
  - No obscuration.



Infrared Aft Optics

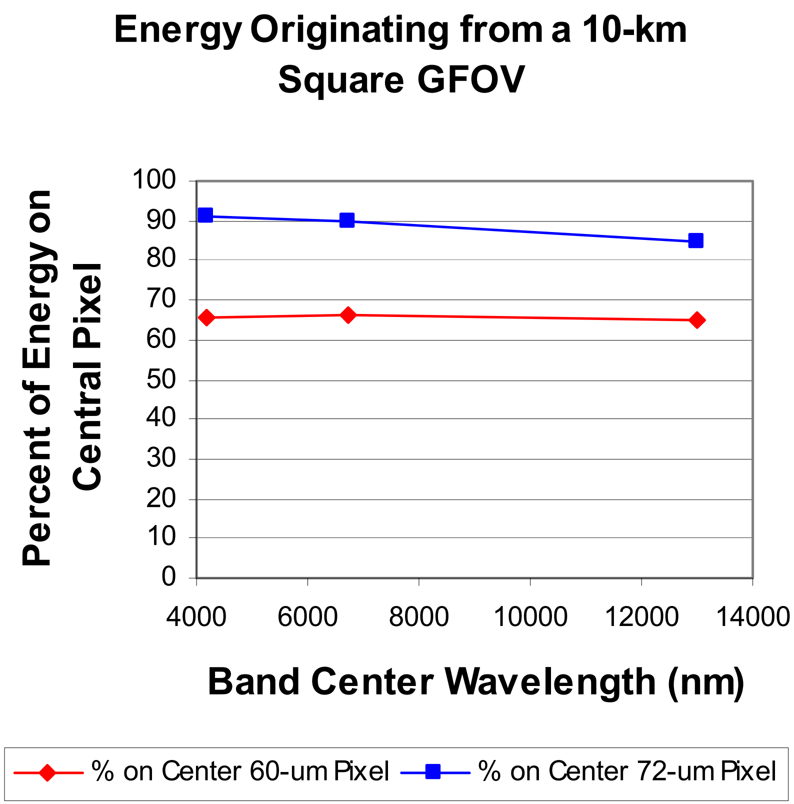
- Catadioptric *f*/0.86 field-imaging design, 250 x 530-km FOV.
  - Accessible field stops (co-registration)
  - Accessible pupil images (cold stops).
  - 10-km resolution.
  - Detector format, 22 x 48 with 60-μm pixels and 72-μm pitch.

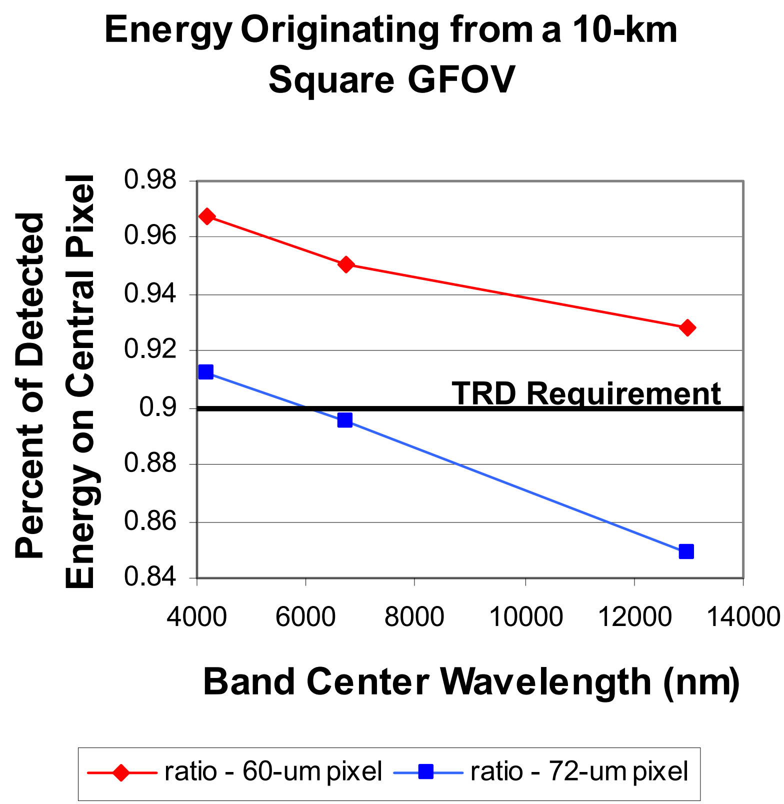


Infrared Channel Performance

- **Three infrared wavebands.**
  - **3.69-4.65 μm, 5.75-8.26 μm, 8.33-15.38 μm.**
- **Geometrical spot significantly smaller than 60-μm active pixel area.**

Ensquared Energy





Outline

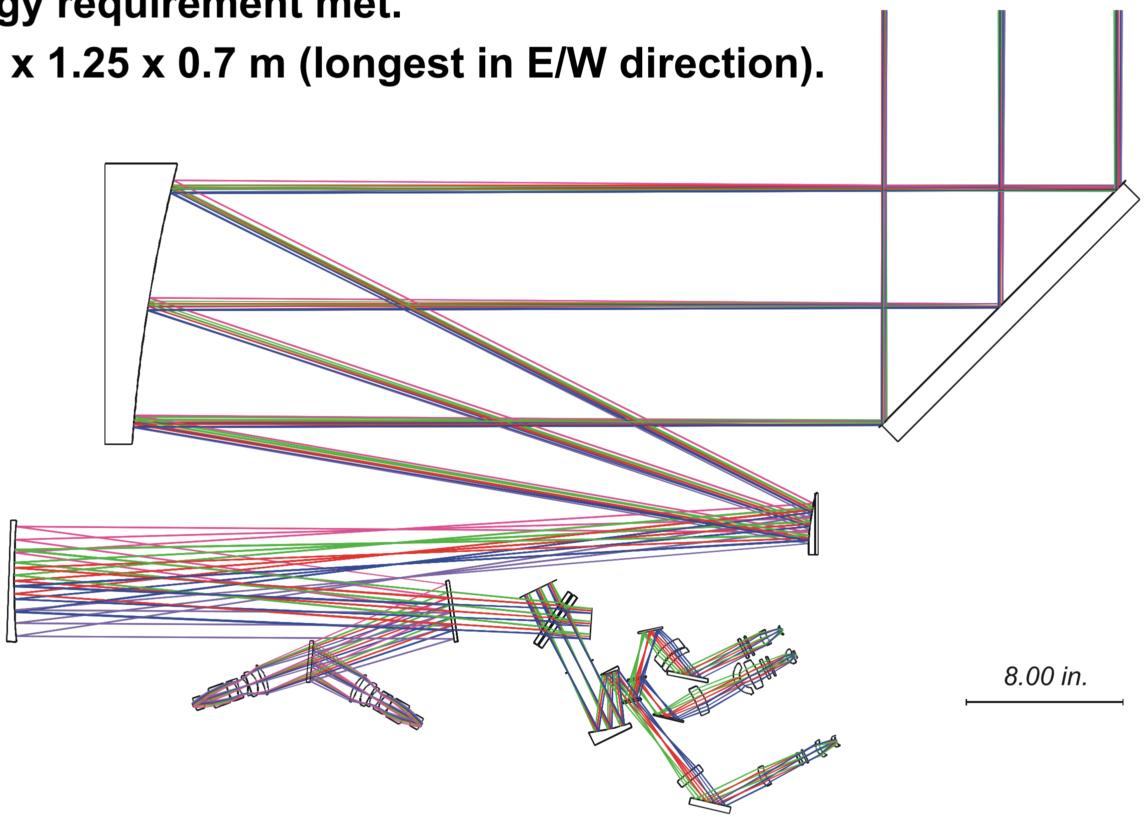
- Introduction.
- System volume progression.
- Optical performance of point design.
  - Visible Optics
  - Infrared Optics
- ➢ Summary.

Upgrade Paths

- Input Telescope
  - Infrared channel FOV is 220 x 480-km.
  - Telescope Design FOV is 500 x 530-km.
- Visible Optics
  - Visible channel FOV of 220 x 480-km matches infrared FOV.
  - Visible optics design FOV is 500 x 530-km.
  - Dedicated low-light channel included.
- Infrared aft optics
  - Infrared Channel FOV is 220 x 480-km.
  - Aft Optics Design FOV is 250 x 530-km.

Summary

- 30 cm (12 inch) aperture diameter.
- FTS system.
- 220 x 480-km field-of-view.
  - 500 x 530-km visible FOV available.
  - 250 x 530-km infrared FOV available.
- Percent energy requirement met.
- Volume = 1.7 x 1.25 x 0.7 m (longest in E/W direction).



ABS Detection and Signal Processing

GOES ABS Industry Day
21 June 2001
Greenbelt, MD

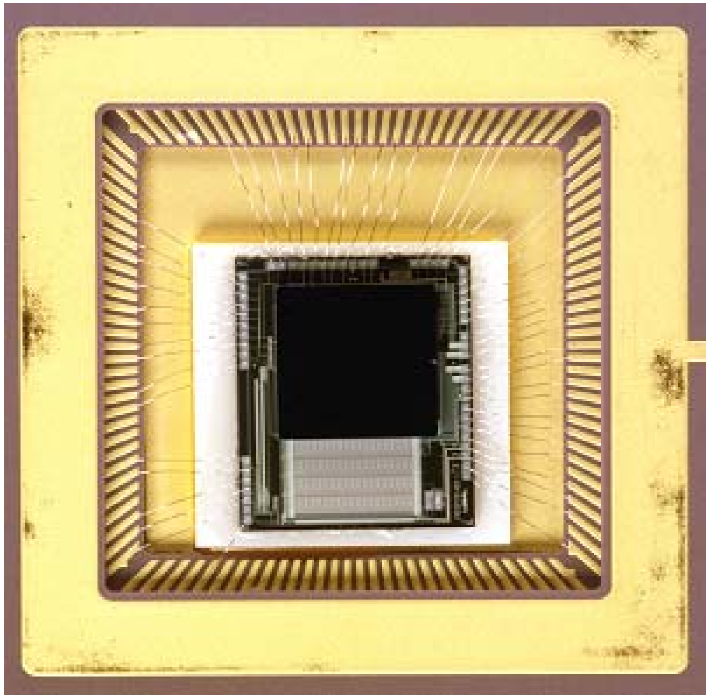
Mike Kelly
Monica Coakley Mike MacDonald

Outline

- FPA design
- Readout noise
- Analog to digital converter
- Signal processing

IR Focal Planes

- Three photovoltaic $HgCd_xTe_{1-x}$ FPA's
  - SW/MW/LW cutoff at 15.1, 8.5, 4.7 μm respectively
  - Detectors operate at 65 K.
  - FPA's share 48 x 22 detector format, 58 μm pixel on 72 μm pitch.
  - Custom readout integrated circuit (ROIC).



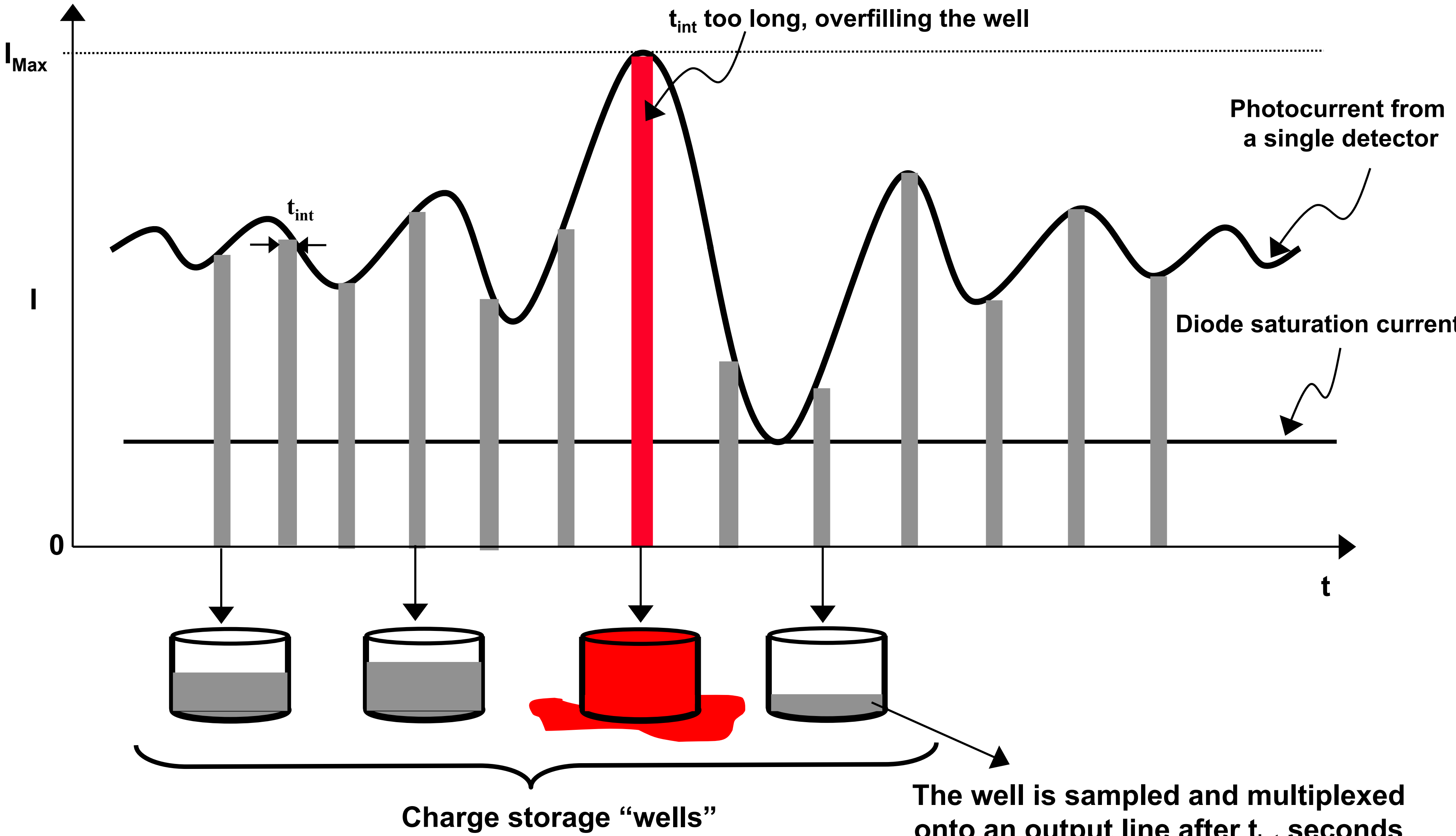
Sample LWIR FPA

- 64x64 array size
- 60 μm pixels, 60 μm pitch
- 15.4 μm cutoff at T=75 K
- BDI preamplifier
- 4x64 Snapshot readout
- 1 MHz readout

Custom Rad-Hard ROIC is an Enabling Technology

- **LW & MW ROIC utilizes large integration capacitors (wells) to integrate large signal flux**
  - Enables the use of slower readout taps
  - Reduced raw data rate eases implementation of downstream electronics required for signal processing
- **16 LW, 8 MW, and 1 SW readout taps**
  - Maximizes noise performance by allowing slow readouts
  - Impacts thermal design by mandating active cooling
- **Buffered direct injection (BDI) LW and MW, capacitive trans-impedance amplifier (CTIA) SW preamplifers**
  - Low noise, highly linear
  - Impacts FPA power dissipation

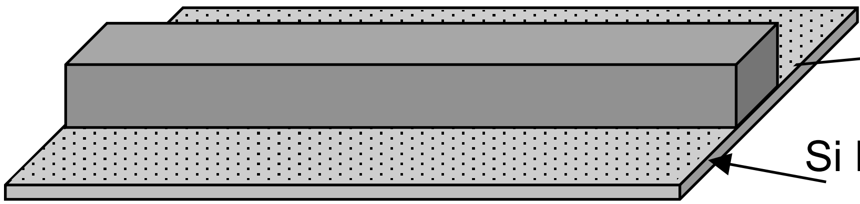
Large FPA Wells are Required to Avoid Overfilling



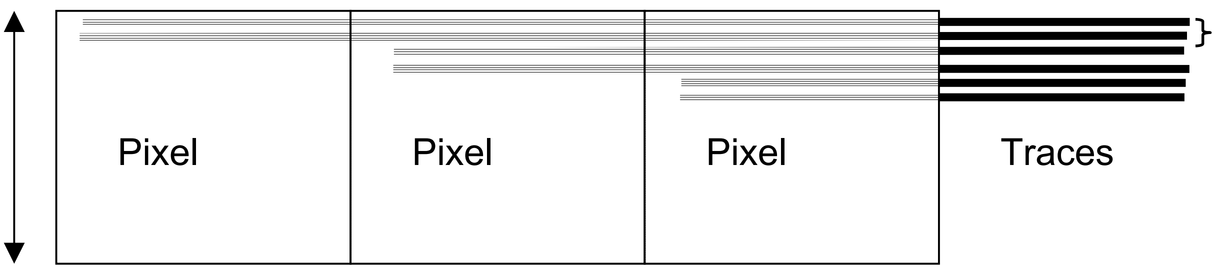
Large LWIR FPA Well Depth is Achieved Using "Off-Chip" Capacitors

- ABS 72 μm pixels ~ 160 million electrons "on-chip" well-depth
  - Capacitor is typically confined to the area beneath a pixel
  - Maximum LW integration time ~ 60 μs
  - Requires 16 1.3 MHz readout taps
- Off-chip capacitor is designed for 380 million electrons capacity
  - Maximum LW integration time ~ 145 μs
  - Requires 16 0.45 MHz readout taps
- Larger capacitors enable:
  - Use of 1.55 μm laser (com industry standard, GHIS & other programs heritage)
  - Use of 0.5 MHz 16 bit ADC
  - Lower raw data rate, less processing and power dissipation
  - Slightly lower NEdN

“Off-Chip” Capacitors are Fabricated on the ROIC Adjacent to Unit Cell Array



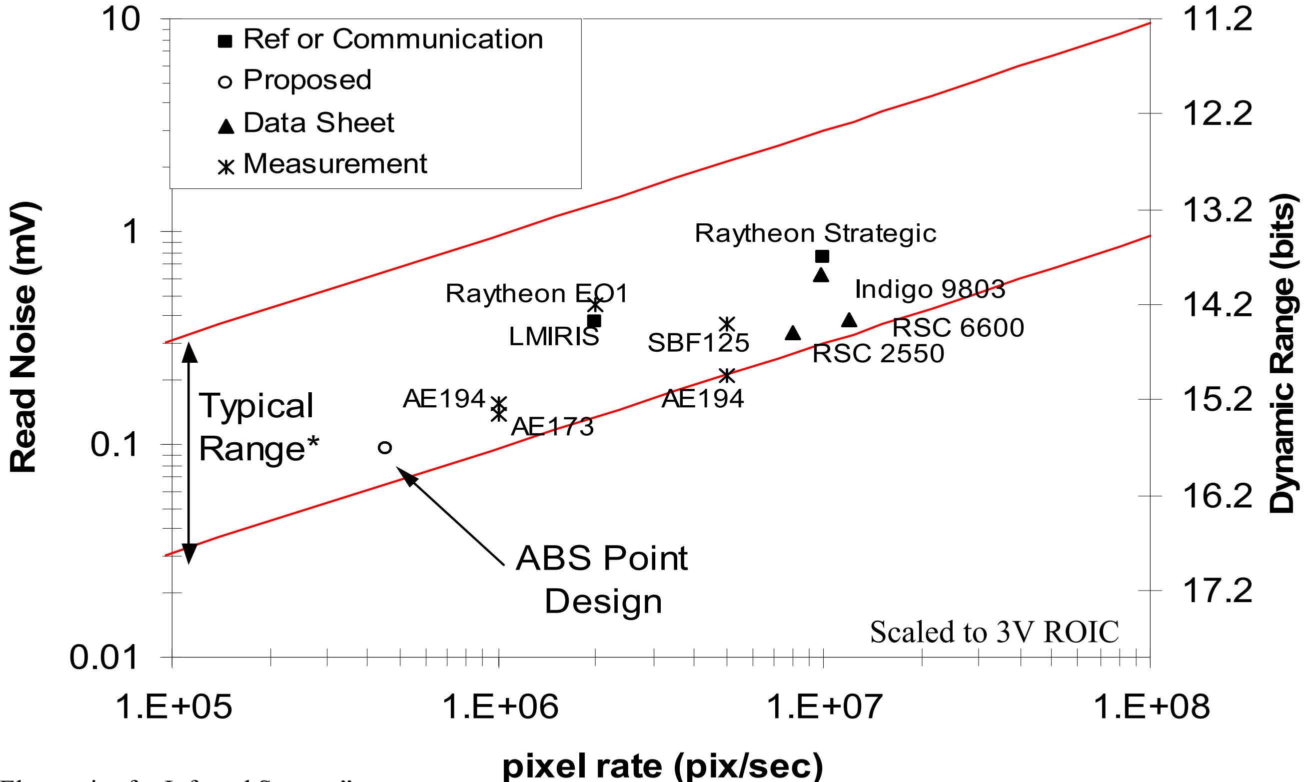
Pixel pitch = 72 μm (defines maximum number of traces out to one side of the FPA)



- **Two traces (3 μm pitch) are required for each capacitor**
- **For a 72 μm pixel, 12 sets of traces would be possible from each side of the FPA**
  - **A total of 24 sets of traces defines the maximum width of the FPA**
- **Technique has been previously demonstrated**

ABS Point Design Assumes Aggressive But Achievable ROIC Noise

- ABS LW & MW FPAs employ 450 kHz readout taps (16)
- 94 μV ROIC noise assumption is achievable for slow rates
- Plot shows typical limits* for ROIC noise vs readout rate compared with demonstrated FPAs



* Vampola J.L., "Readout Electronics for Infrared Sensors", Infrared, Vol. 3. 1993.

FPA Power Dissipation

- Dominated by the ROIC preamplifier and output video driver.

$$P_{FPA} = N_{pixels}\, P_{preamp} + 3\, C_{load}\, \Delta V^2\, N_{outputs}\, f_{frame}$$

- Assume 40 μW preamplifier power dissipation for every pixel in each FPA (conservative).
- Output amplifier power dissipation is determined by cable load capacitance, output rate, number of outputs, signal voltage, and design type.
- Assume source-follower outputs with following parameters:
  - 500 pf cable capacitance
  - 16 - 450 kHz LWIR taps, 8 - 450 kHz MWIR taps, 1 - 7,270 kHz SWIR taps.
  - 3 volts maximum signal.
  - Each array always powered and reading out maximum signal.
- Power dissipation estimate:
  - LWIR = 140 mW, MWIR = 90 mW, SWIR = 140 mW.

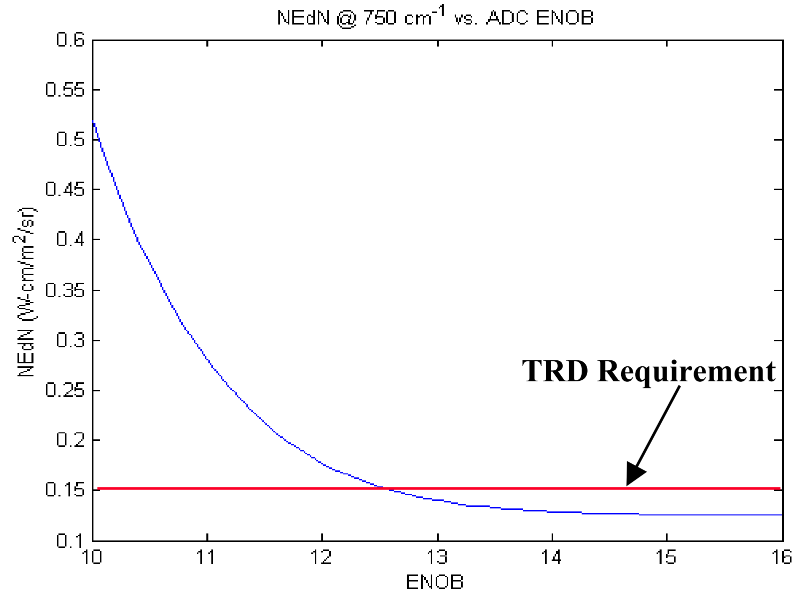
16-Bit A/D Converters for FPA's

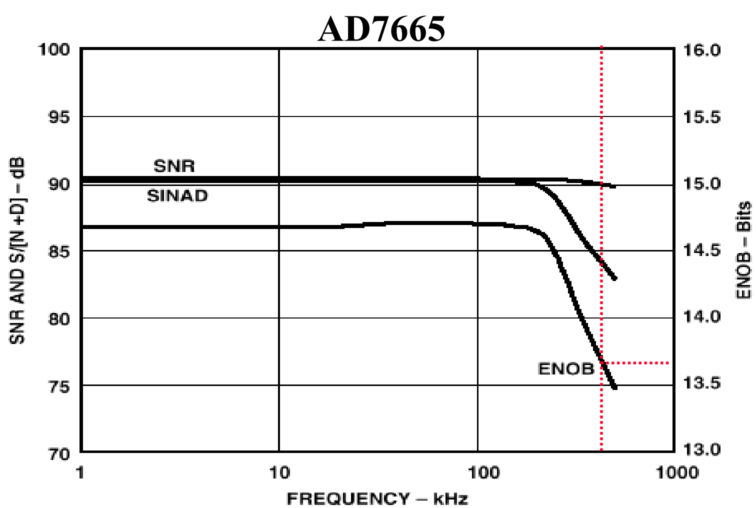
- **LWIR & MWIR channels require 16 bits to meet NEdN.**
  - **Reduces quantization noise below detector noise.**
- **No space-qualified part available.**
- **Several Analog Devices ADCs could meets SNR requirements**
- **Commercially-available 16-bit A/D would need to be repackaged, and shielded.**
  - **Point design assumes these measures are implemented.**
  - **Shielding mass (thick aluminum electronics box) may be substantial, but not yet quantified.**

Part Number	Throughput MSPS	Power Dissipation mW (max)
AD7664	0.57	115
AD7665	0.57	115
AD7671	1.0	120
AD7676	0.5	75

ABS LW NEdN vs. ADC Effective Number of Bits (ENOB)

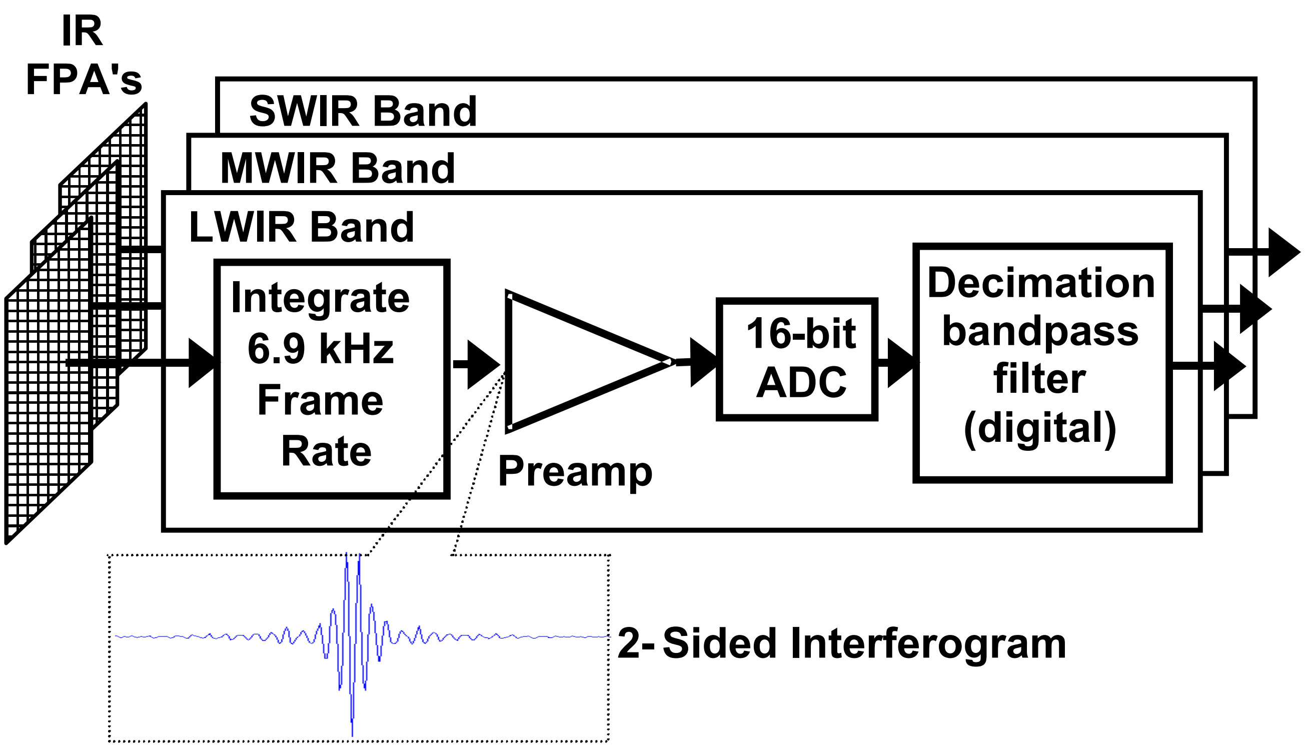
- **ENOB > ~ 13.5 is optimal**
- **NEdN model assumes 13.5 ENOB**
- **AD7665 can meet this expectation**
  - **Some other potential parts are preliminary and need to be quantified**
- **A 14 bit part (AD9240) can provide ~ 11.6 – 12.3 ENOB**





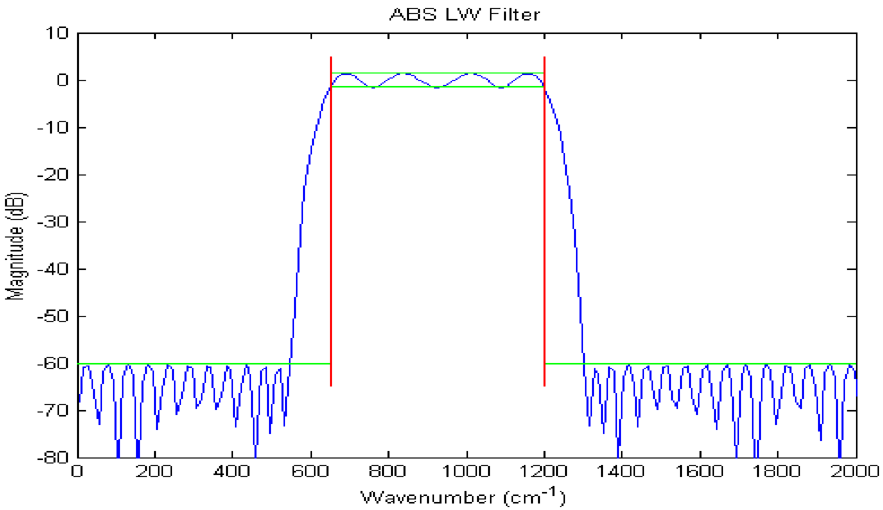
IR Signal Processing Electronics

- FPAs integrate interferogram samples for low pass filtering
- An amplifier scales the FPA output appropriately for the ADC
- The over-sampled interferogram is filtered and decimated, without loss to spectral data, to fit into data rate allocation



Longwave
Signal Processing Implementation

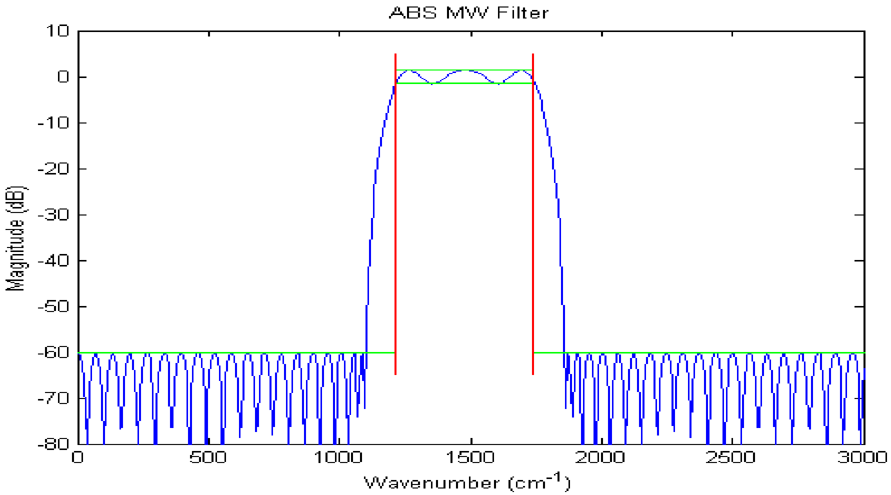
- **2 samples per laser fringe**
  - **23x oversampled**
  - **16 bit ADC samples**
- **1 stage filter design**
  - **Decimate by 20**
  - **236 tap complex bandpass filter**
  - **3 db pass band ripple**
  - **-60 dB aliasing attenuation**
- **2 memories 4 FPGAs**
- **4 cards (2 memory/FPGA, 2 ADC)**
- **6.1 watts power dissipation**



Totals		
Storage Required	708	Kbytes
Access Rate	180.35507	Mbytes/sec
Memory Required	2	Chips
Req Access Time	44.356945	ns
Memory Power	3.6071014	Watts
Multiply Rate	83.132416	Mop/s
# Multipliers	3.990356	
#FPGA's	4	
Power	2.4939725	Watts
Total Power	6.1010739	Watts

Midwave
Signal Processing Implementation

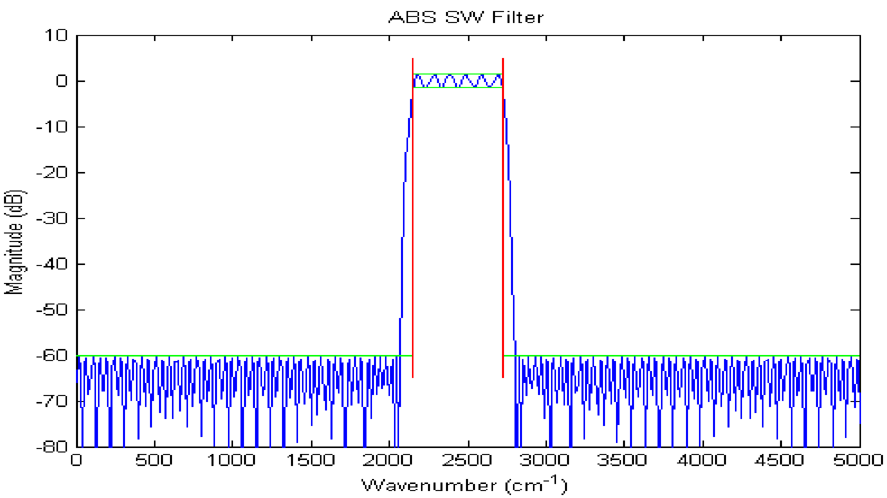
- **1 sample per laser fringe**
  - **12x oversampled**
  - **16 bit ADC samples**
- **1 stage filter design**
  - **Decimate by 10**
  - **98 tap complex bandpass filter**
  - **3 db pass band ripple**
  - **-60 dB aliasing attenuation**
- **1 memory 2 FPGAs**
- **2 cards (memory/FPGA, ADC)**
- **2.6 watts power dissipation**



Totals		
Storage Required	294	Kbytes
Access Rate	76.087296	Mbytes/sec
Memory Required	1	Chips
Req Access Time	52.571194	ns
Memory Power	1.5217459	Watts
Multiply Rate	34.521088	Mop/s
# Multipliers	1.6570122	
#FPGA's	2	
Power	1.0356326	Watts
Total Power	2.5573786	Watts

Shortwave
Signal Processing Implementation

- **2 sample per laser fringe**
  - **22x oversampled**
  - **12 bit ADC samples**
- **1 stage filter design**
  - **Decimate by 20**
  - **292 tap complex bandpass filte**
  - **3 db pass band ripple**
  - **-60 dB aliasing attenuation**
- **2 memories 5 FPGAs**
- **2 cards (memory/FPGA/ADC)**
- **7.5 watts power dissipation**



Totals		
Storage Required	584	Kbytes
Access Rate	219.80774	Mbytes/sec
Memory Required	2	Chips
Req Access Time	36.395442	ns
Memory Power	4.3961549	Watts
Multiply Rate	102.85875	Mop/s
# Multipliers	4.9372201	
#FPGA's	5	
Power	3.0857626	Watts
Total Power	7.4819174	Watts

Summary

- FPA design leverages detector array state-of-the-art, and knowledge gained in MIT/LL test efforts
  - 48 x 22 detector pixel photovoltaic $HgCd_xTe_{1-x}$ FPA's
  - Cutoffs at 15.1, 8.5, 4.7 μm respectively at 65K
  - 58 μm pixels on 72 μm pitch
- LWIR and MWIR Readout noise must be minimized, requiring custom ROIC
  - ROIC utilizes existing technology for large capacitors, not physically under pixel, to integrate signal flux
- 16-bit Analog to digital converters are required in the LWIR and MWIR channels to meet NEdN thresholds
  - Reduces quantization noise below detector noise
- Signal processing implementation is efficient, minimizing power and card count

ABS Mechanical and Thermal Design

GOES ABS Industry Day
21 June 2001
Greenbelt, MD

Darryl Weidler,
Mike MacDonald

MIT Lincoln Laboratory

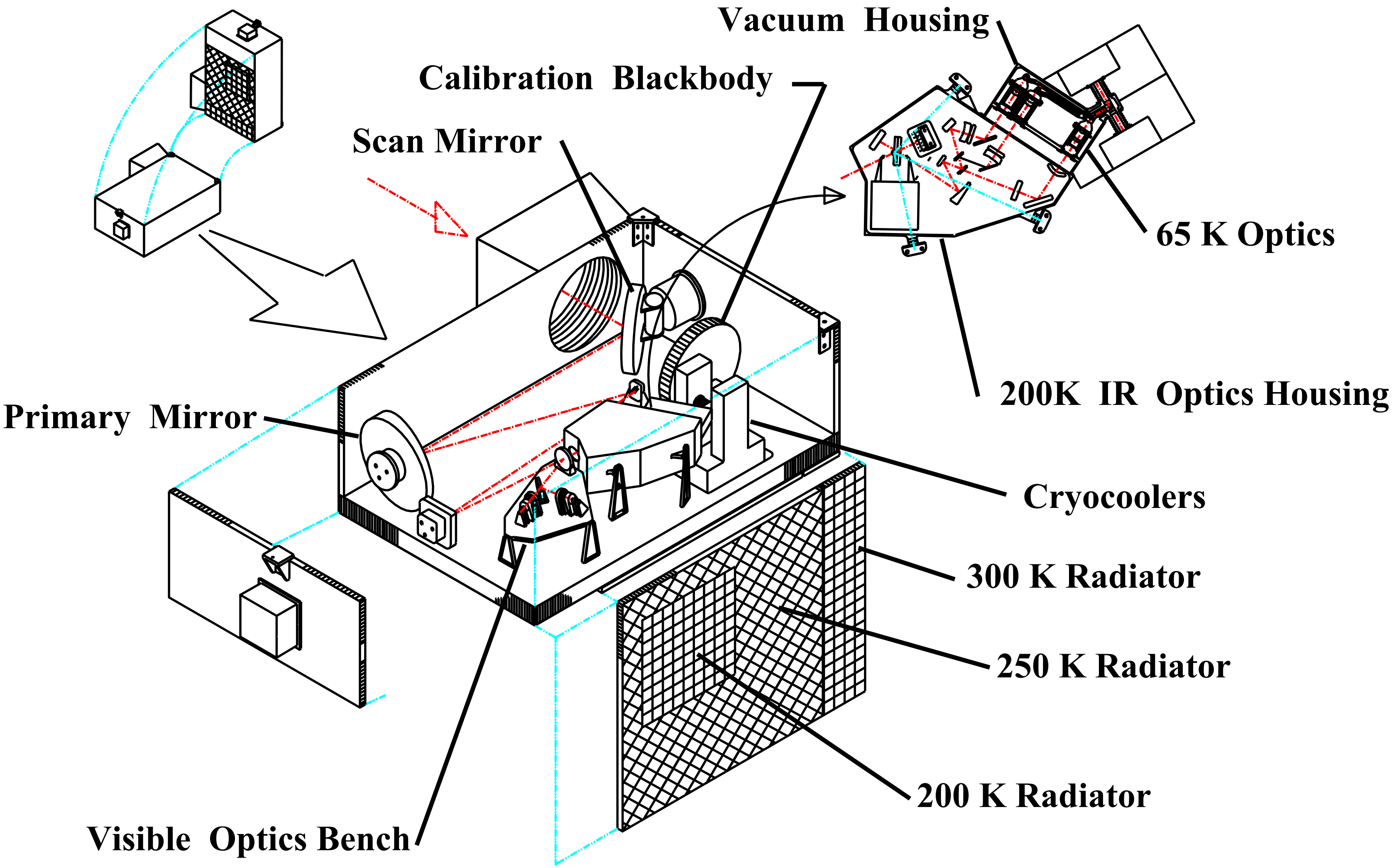
Overview

- The single most fundamental design change over earlier MIT/LL point designs is the use of mechanical cryocoolers.
  - Enabling technology for large, cold, IR FPA's.
  - Increased sensor power consumption.

- The sensor volume and mass are largely dictated by the optical layout.

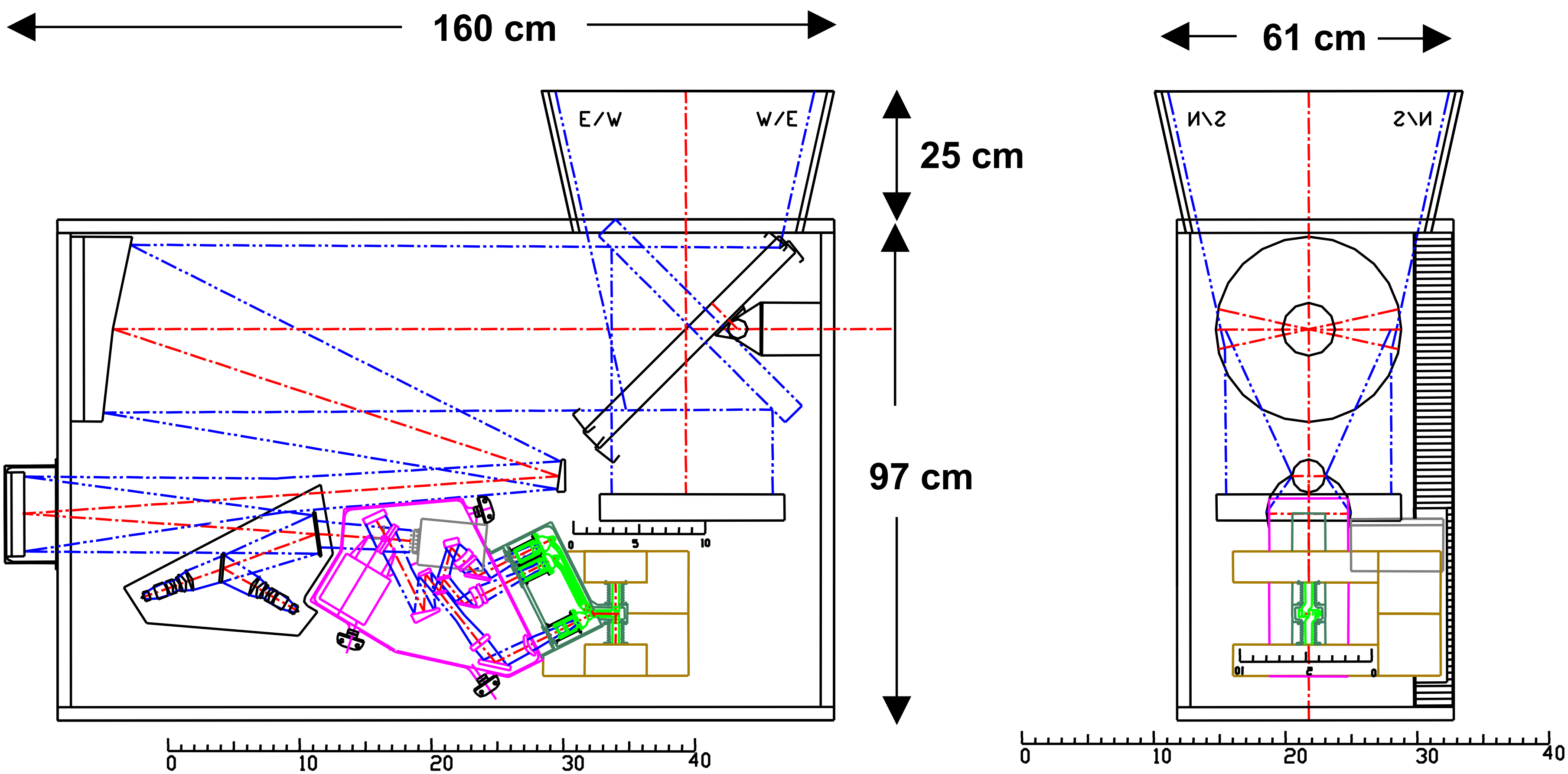
- Cryocooler integration requires creative solutions to several problems:
  - Vacuum dewar for detectors.
  - Vibrational decoupling of detectors from cryocoolers.
  - Thermal decoupling between cryocooler and aft optics portions of vacuum housing.
  - Maintaining warm-to-cold alignment in the detectors and aft optics.

ABS Exploded View



(Electronics module not shown)

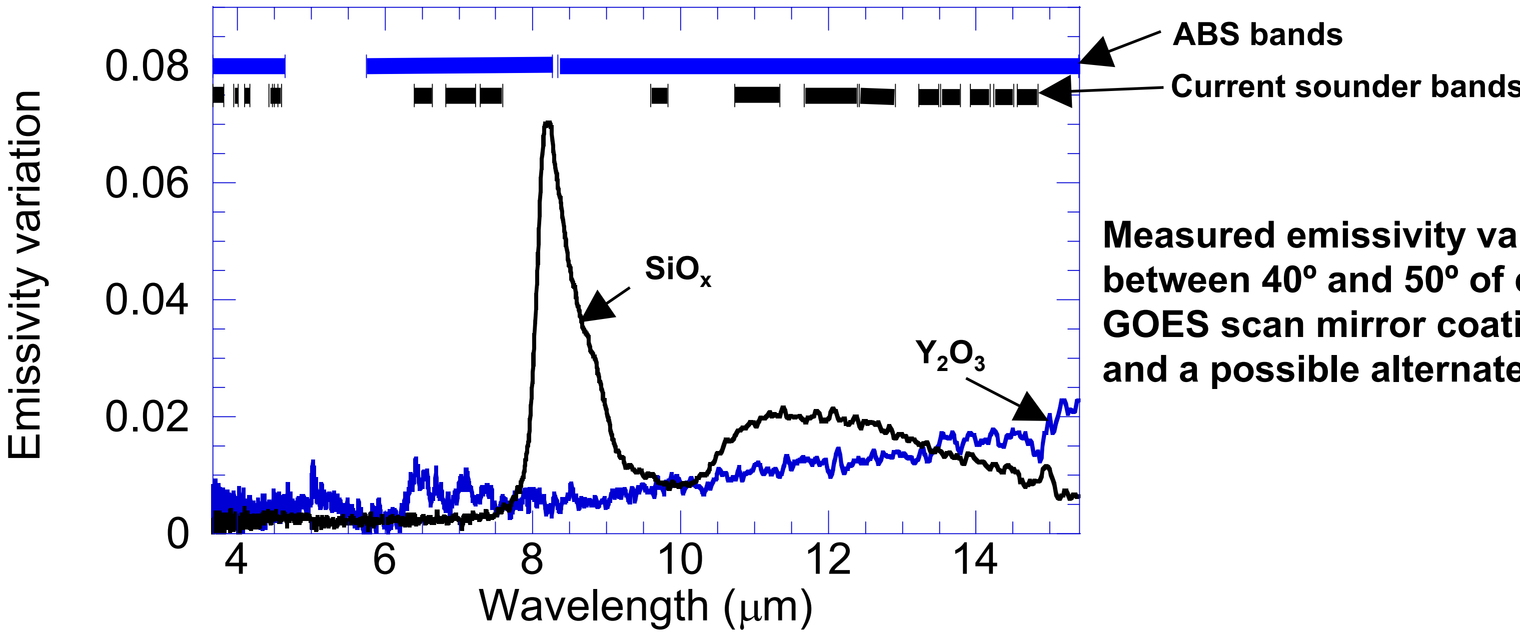
ABS Volume



Scale in inches

Scan Mirror

- Low-distortion SiC substrate (slightly larger than GIFTS).
  - CTE of SiC is about four times lower than for beryllium.
  - Stiffness of SiC is up to twice that of beryllium.
  - Silicon polishing layer CTE is well-matched to SiC.
- Low-emissivity coating (Aluminum overcoated with Y_2O_3).
  - ABS spectral coverage includes large absorption feature in SiO_x which has been avoided in earlier imagers and sounders.



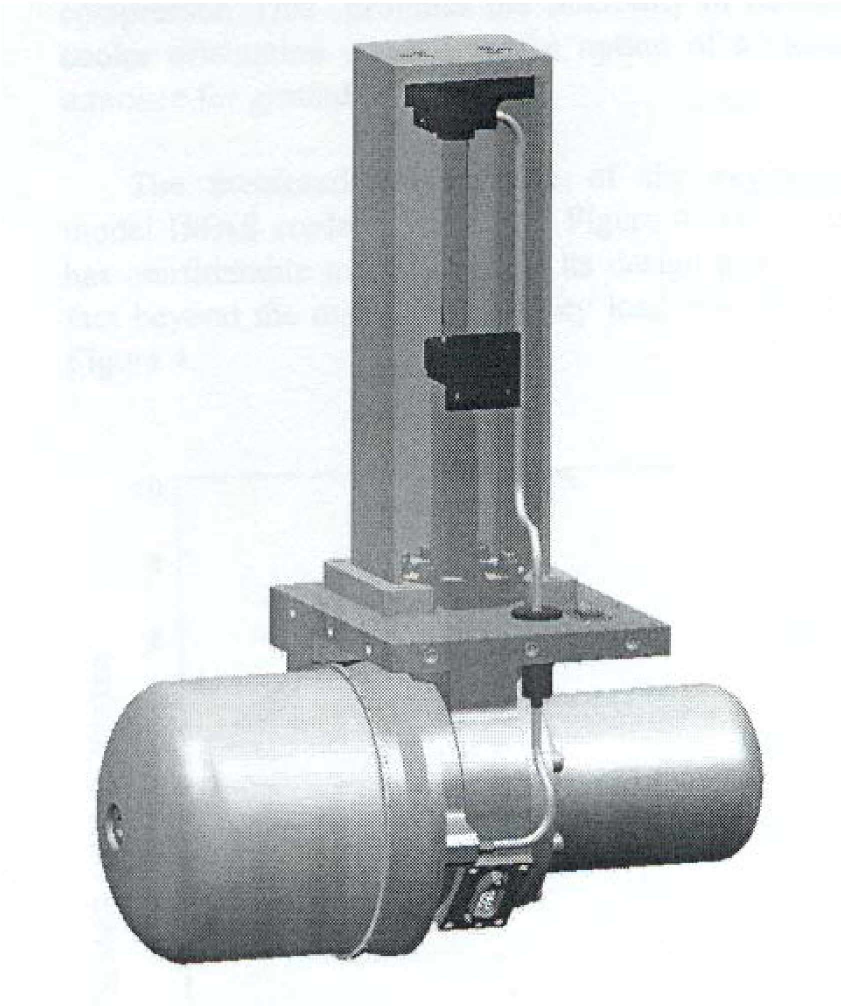
Measured emissivity variation between 40º and 50º of current GOES scan mirror coating (SiO_x) and a possible alternate (Y_2O_3).

Sensor Cooling Overview

- Cryocoolers are used for IR detector arrays.
  - Highest-reliability configuration (redundant coolers w/o heatswitches, redundant electronics).
- Passive thermal radiators are used for ambient and near-ambient heat loads.
  - Highly efficient at T > 200 K.
  - Ample space available for radiators.
  - No need for multi-stage cryocooler cold head.

Pulse-Tube Cryocooler

- "High Efficiency" Compressor and electronics - as in GIFTS.
- 60 K cold head operating temperature.
  - FPA control temperature is 65 K.
- A single cold head is used in place of the GIFTS two-stage pulse tube.
  - SBIRS-Low design.
  - No need to refrigerate 200 K cold optics with cryocooler.
- Cooler efficiency maximized by rejecting heat to 250 K.
  - Within qualification range of cooler.
  - Reduced sensor power consumption.



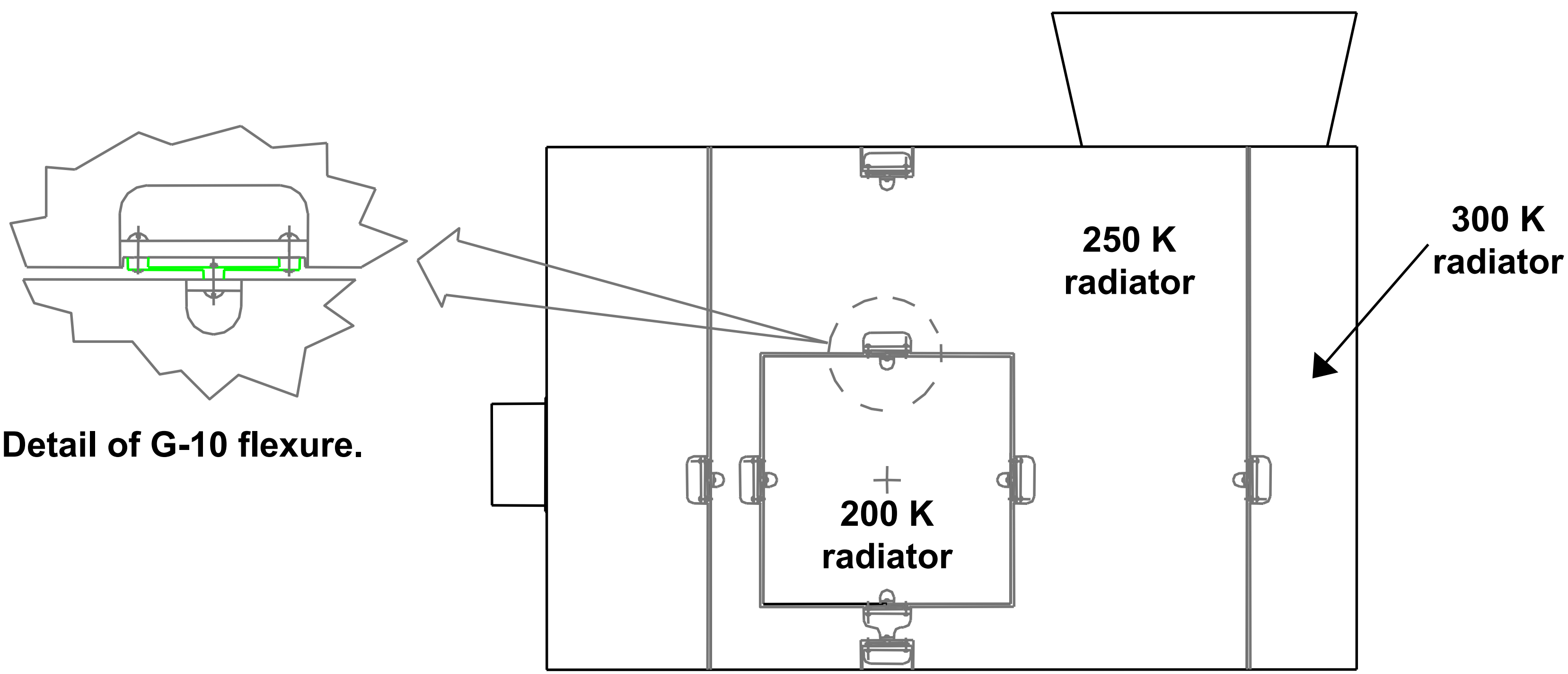
Source: AIAA Proceedings.

ABS Thermal Budget: Cryocooler Load

Description	Power	Notes
Dissipated Loads		
SW FPA dissipation	0.15 W	60 mW margin, 65 K control temp.
MW FPA dissipation	0.15 W	60 mW margin, 65 K control temp.
LW FPA dissipation	0.20 W	60 mW margin, 65 K control temp.
FPA control power	0.15 W	Control each FPA to ~10 mK
Parasitic Loads		
Redundant CC load	0.8 W	Cold head not optimized for 60 K
65K conduction load	0.16 W	Fiberglas-epoxy FPA supports
65K radiation load	0.16 W	Housing, filter, FPA, cold straps
FPA wires	0.07 W	100 constantan wires total
Subtotal	1.85 W	
Margin	0.65 W	35%
Total cryocooler load	2.5 W	60 K cold-tip temperature

Passive Radiative Coolers

- Radiator sizing assumes yaw flip at equinoxes.
  - 200 K radiator requires sunshield otherwise.
  - Other radiators would require modest size increase.
- Radiators mounted using G-10 flexures for thermal isolation.
- Radiator sizing includes thermal emission from 4x1 m solar array.



Detail of G-10 flexure.

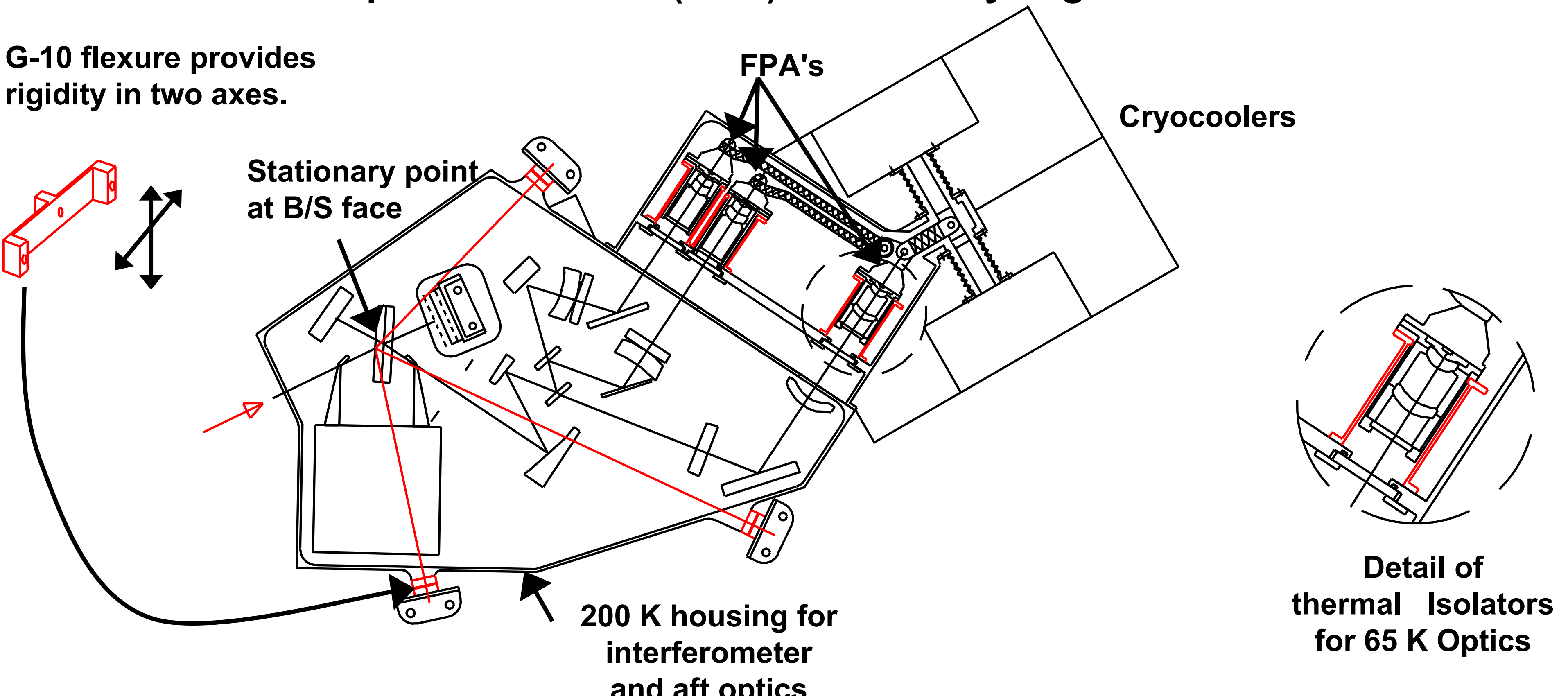
ABS Thermal Budget: Radiator Loads

Description	Power	Notes
Ambient Radiator	40 W total @ 300 K	Area = 0.11 sq. meters
Interferometer mirror	8 W	Mechanism dissipation
Scan motor	20 W	
Metrology source	4 W	Laser dissipation
Sensor electronics	7.5 W	IR preamplifiers
250 K Radiator	70 W total @ 250 K	Area = 0.41 sq. meters
Cryocooler compressor	50 W (20 W/W sp. Power)	Within qual. Temp. range
Cryocooler EOL margin	10 W	EOL growth allowance
Calibration blackbody	10 W	Controlled at 290 K
200 K radiator	10.2 W total @ 180 K	Area = 0.22 sq. meters
Radiation from 300 K to housing	4.60 W	IR ass'y & vacuum housing
Radiation thru housing apertures	2.38 W	Moving mirror & IR beam
Conduction thru housing supports	0.15 W	G-10 flexures to 300 K
Conduction thru SS bellows	0.23 W	Vib. Isolators to 250 K
Radiation input from Earth	0.07 W	Emission & refl. Solar
Radiation input from solar array	3.07 W	1x4m, 1m from radiator
Heat loss to 65 K	(-0.32 W)	

Areas based on α = 0.17 EOL, ε = 0.78 EOL.

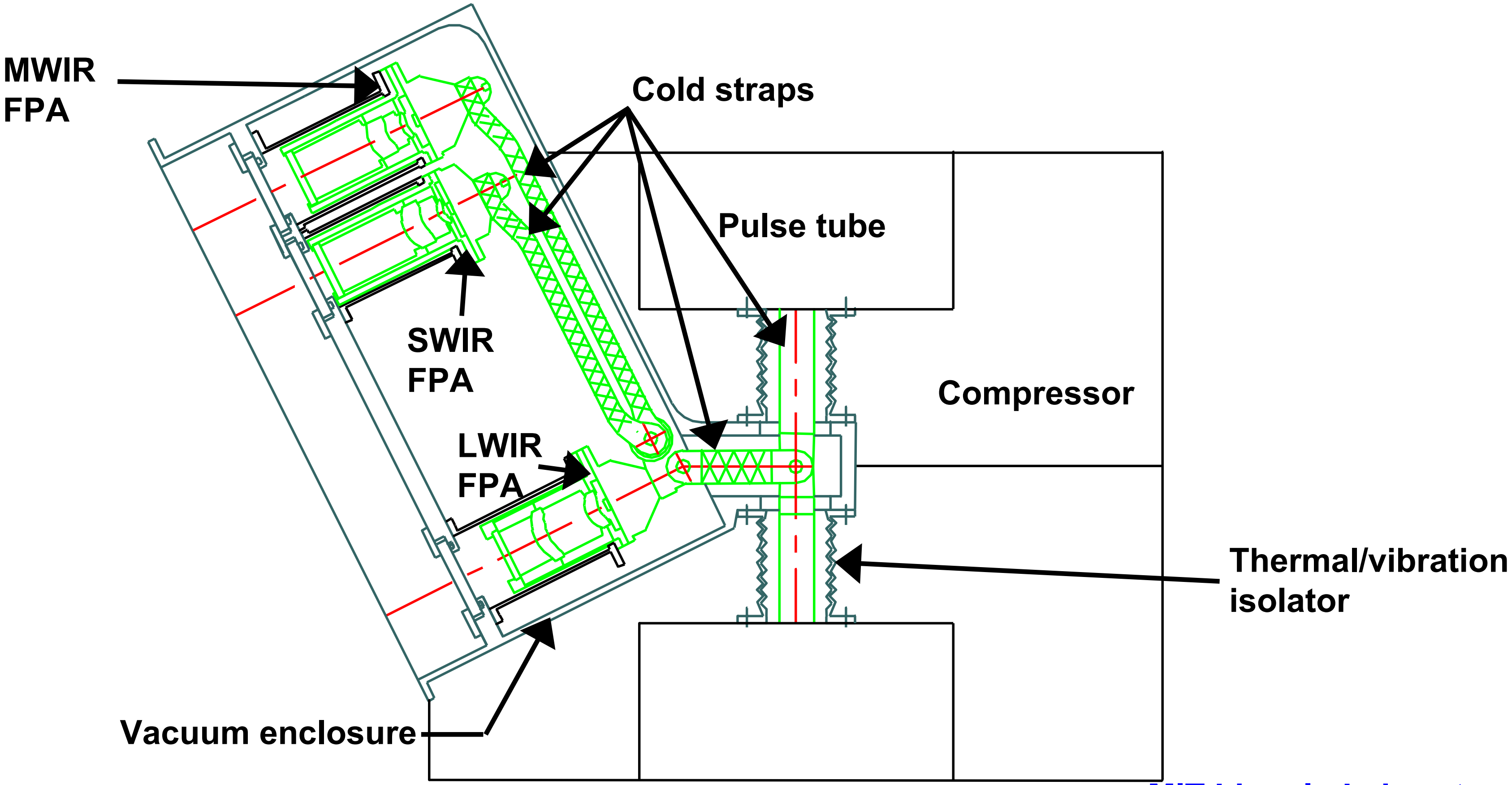
Optomechanical Overview

- **Fiberglas flexures used to provide kinematic mounts**
  - **Cold optics (200 K) maintain alignment with ambient bench via face of interferometer beamsplitter.**
  - **Aft optics and FPA's (65 K) individually aligned on IR beams.**



Vacuum Dewar and Cold Links

- **A vacuum enclosure houses the lowest temperature zone (60 K cold heads, 65 K LWIR FPA, 70 K SWIR/MWIR FPA's)**
  - **Vibrational decoupling through bellows, cold flex link.**
  - **Enclosure attaches to 200 K cold optics module.**



Sensor Mass Estimate

Description	Mass (Kg)
Input aperture cover	5.5
Radiator cover	2.5
Optical bench (3" Al. honeycomb)	11.0
Ambient optics assemblies	13.9
200 K optics assembly	11.2
65 K optics assembly	1.5
Blackbody calibration source	1.2
Scan mirror (SiC 50% LW)	10.2
Scan motor assembly	3.0
Baffles, internal & external	9.1
Housing (1" Al. honeycomb)	16.6
Moving mirror assembly	1.8
Radiation shielding	0.1
Magnetic shielding	0.9
Cryocoolers (2)	8.0
Passive thermal radiators	8.6
Sensor estimate	105.1
20% Contingency	21.0
ABS sensor total mass	~126

System Mass Estimate

- **Estimated system mass is ~ 200 kg, divided roughly 2/3 - 1/3 between sensor and power supplies/electronics.**

Description	Mass (Kg)
Power supplies (redundant set of 2 in shielded enclosures)	10.0
Sensor control electronics (redundant set of 13 6" x 8" boards at 0.5 kg per board)	13.0
Cryocooler electronics (redundant)	11.0
Signal processing electronics (redundant set of 8 6" x 8" boards)	8.0
Cables (estimate)	4.5
Power supplies & electronics estimate	46.5
20% Contingency	9.3
ABS electronics total mass	~56
ABS sensor total mass	~126
ABS system total mass	~185

ABS Electronics Power Estimate

Description	Power	Notes
Instrument control processor	1 W (0.2 A @ 5 V)	8 bit μp
FPA timing logic	1.5 W (0.3 A @ 5 V)	ASIC
FPA drive signals	12.0 W (0.4 A @ +&- 15 V)	analog electronics
LWIR signal processing	16 x 0.8 W (0.01 A @ +&- 15 V, 0.1 A @ 5V)	Preamps and 16-bit A/D's
	6.1 W (1.22 A @ 5 V)	Memory & FPGA's
MWIR signal processing	8 x 0.8 W(0.01 A @ +&- 15 V, 0.1 A @ 5V)	Preamps and 16-bit A/D's
	2.6 W (0.52 A @ 5 V)	Memory & FPGA's
SWIR signal processing	1 x 0.8 W(0.01 A @ +&- 15 V, 0.1 A @ 5V)	Preamp and 14-bit A/D
	7.5 W (1.5 A @ 5 V)	Memory & FPGA's
VIS signal processing	0.6 W (0.01 A @ +&- 15 V, 0.05 A @ 5V)	preamp and 14-bit A/D
Scan mirror motor	20 W (0.67 A @ +&- 15 V)	
Scan mirror servo	2.5 W (0.05 A @ +&- 15 V, 0.2 A @ 5V)	Sensor, A/D and DSP
Michelson moving mirror	8 W (0.27 A @ +&- 15 V)	
Moving mirror servo	6 W (0.15 A @ +&- 15 V, 0.3 A @ 5V)	Includes metrology
VIS CCD thermal controllers	5.0 W (0.03 A @ +&- 15 V, 0.8 A @ 5V)	
IR FPA thermal controller	4.5 W (0.015 A @ +&- 15 V, 0.8 A @ 5V)	
5V Conditioned power	42.0 W (8.39 A @ 5 V)	
15 V Conditioned power	55.4 W (1.85 A @ +15 V / 1.85 A @ -15 V)	
Power supply	32.5 W (75% efficiency)	

ABS System Power Estimate

Description	Power	Notes
(Sensor Electronics)	90 Watts	Sunk to sensor
Scan mirror motor	20 W	ambient
Interferometer mirror motor	8 W	ambient
Interferometer metrology	4 W	ambient
IR signal preamplifiers	7.5 W	ambient
Cryocooler compressor	50 W (20 W/W sp. Power)	250 K
(External Electronics)	130 Watts	Sunk to bus (ambient)
Scan mirror servo	2.5 W	
Moving mirror servo	2.0 W	
Instrument controller	1.0 W	
FPA timing and drive	13.5 W	2 CCD's, 3 FPA's
IR A/D & signal processing	28.7 W	Post preamplification
Vis signal processing	0.6 W	
Vis CCD thermal control	4.8 W	2 CCD's
IR FPA thermal control	4.5 W	3 FPA's
Cryocooler electronics	20 W	
Cryocooler EOL margin	20 W	
Electronics power supply	32.5 W	
TOTAL	~220 Watts	

Conclusion

- The mechanical and thermal design of ABS is driven by the presence of mechanical cryocoolers, and by a wide-field and low *f*-number optical system.

- This design presents a number of challenges with respect to accomodation alongside ABI on a future bus:
  - Mass of ~ 185 kg using conservative budgeting.
  - Power of ~ 220 W incorporating margin.
  - Volume of ~ 1.7 x 0.7 x 1.25 meters, longest in the E-W direction.
  - Thermal budgeting for radiators assumes no solar input (e.g. the use of a yaw flip).
    - 200 K radiator requires sunshade otherwise.
  - Thermal budgeting includes emission from a 4 x 1 meter solar array in the radiator FOV.

ABS Point Design Summary

GOES ABS Industry Day
21 June 2001
Greenbelt, MD

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Point Design Summary

- The point design presented here meets all TRD requirements.
- Challenging requirements have led to a challenging design.
  - More inclusion of technological and fabrication risk than previous designs.
  - Heavy dependence on GIFTS to validate key technologies.
- Incorporation of ABS and ABI on a common platform is challenging, given instrument parameters.
  - 530 x 500 vis. Field / 530 x 250 IR field / 480 x 220 IR FPA field (possible upgrade path).
  - NEdN (NESR) of 0.13 $mW/(m^2\ sr\ cm^{-1})$ at LWIR band center assuming median FPA D* and 289 K blackbody.
  - 30 cm (12 inch) aperture diameter.
  - Mass = 185 kg.
  - Power = 220 W.
  - Volume = 0.7 x 1.25 x 1.7 m (longest in E/W direction).
  - Data rate = 9.93 Mbps.

Comments on Requirements and Risk

- **Some risky design elements (e.g. 16-bit A/D's) are dictated *exclusively* by NEdN requirements.**
- **Some large accomodation impacts (e.g. volume & mass) are dictated by NEdN in concert with required coverage.**
- **Potential Phase-B trades could explore these aspects in more detail:**
  – **Modest increase in NEdN with 14-bit A/D's.**
  – **Modest increase in NEdN with reduced optical field.**
  – **Meeting coverage rate at a relaxed NEdN while meeting threshold NEdN in "mesoscale" or other regional coverage mode.**
- **Ten-year design life is a paramount concern.**

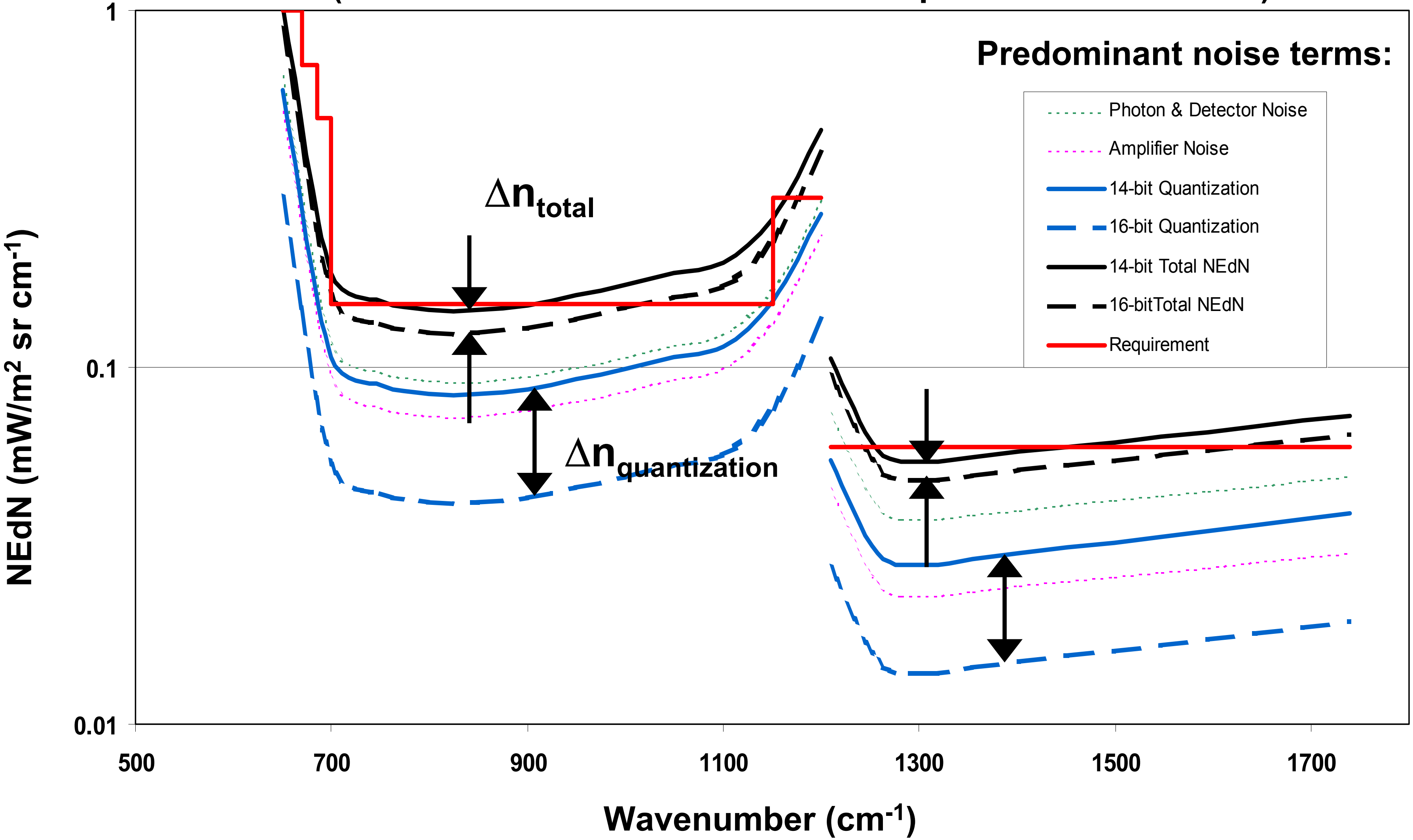
Spacecraft Accomodation

- ABS point design is likely to place greater stress on the system integrator than ABI, except for data rate.
  - If GIFTS requirements are injected, ABS may greatly exceed ABI in data rate as well.
- This resulted from the more stringent coverage rate and NEdN requirements in the TRD.
  - Earlier ABS point designs were less stressing than the GOES-I sounder in mass, power, and volume.

GOES-I Imager	GOES-I Sounder	ABI	ABS 1999/2000	ABS 2001
120 Kg	126 Kg	~120 Kg	80/110 Kg	185 Kg
120 W	105 W	~120 W	70/90 W	220 W
1.2 x 0.8 x 0.8 m	1.4 x 0.8 x 0.8 m	~GOES-I	0.6 x 0.8 x 0.8 m	1.7 x 1.25 x 0.6 m
2.6 Mbps	0.04 Mbps	15 Mbps	2.5 Mbps	10 Mbps
Passive	Passive	Passive?	Passive cooling	Active cooling

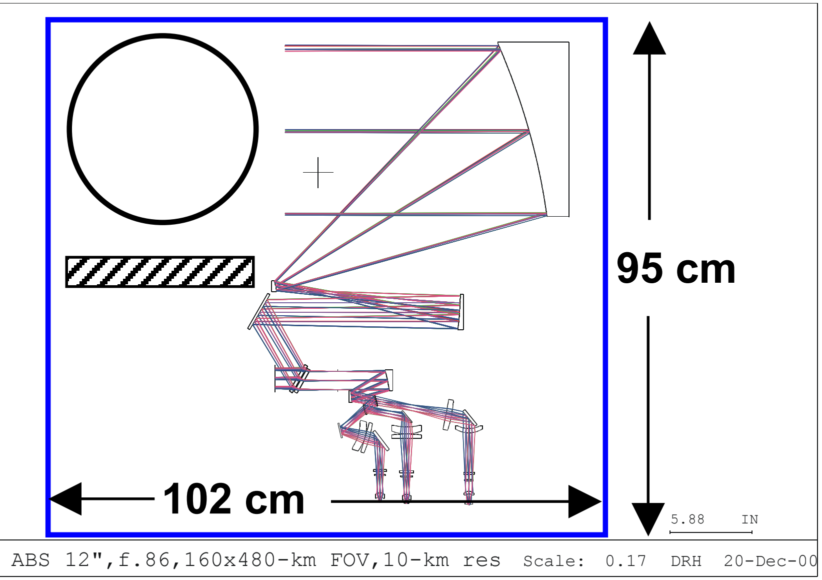
14-bit ADC's Marginally Degrade NEdN, but Exceed TRD Threshold

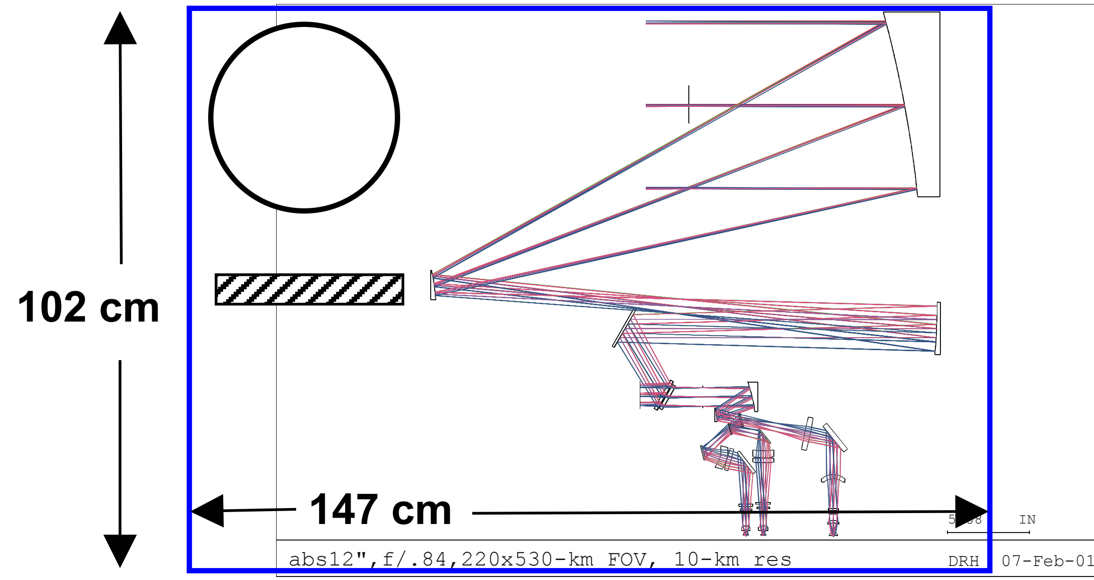
(SWIR not shown because baseline quantization is 14 bits)



Growth in Volume with Optical Field

- **During the design process, the sensor volume exceeded the 1m^3 goal envelope.**
  - **Optics volume increased ~50% with 50% increase in field.**
  - **Implies a ~50% relaxation in coverage rate (or ~20% relaxation in NEdN) would return form factor to 1m^3.**
  - **Final optical design was 530 x 250 km IR / 530 x 500 km vis., chosen to provide some upgradeability.**





Critical ABS Issues

- Operational requirements (coverage rate and NEdN) combine to challenge achievable technology.
  - Fast, wide-field, off-axis optics.
  - Large, low-noise, low-outage focal plane arrays.
  - Fast, low-noise readouts.
- Scientific capability embodied in the TRD has been purchased at the cost of technology and fabrication risk.
  - An inherently aggressive ("NMP-ish") design is mandated.
  - Optics occupy substantial volume and will be difficult to build.
  - Detector outages limit growth of aperture.
  - Further cooling of (BLIP) detectors achieves little.
  - ROIC electronics and A/D push state of the art for S-class.
- Lifetime requirements highlight key components.
  - Cryocoolers.
  - Metrology laser.

Conclusion

- The January TRD contained ~ factor of 3 upgrades in both coverage and NEdN.
- An ABS point design has been generated which meets TRD threshold requirements.
  - No attempt has been made to minimize the difficulty of spacecraft accomodation.
  - Risk has been minimized wherever possible while meeting TRD thresholds.
- Four data points exist which correlate instrument architecture with science requirements:
  - 1999 ABS point design.
  - 2000 ABS point design.
  - 2001 ABS point design.
  - GIFTS.
- Science benefit versus difficulty of procurement and S/C accomodation can be parameterized along these data points.